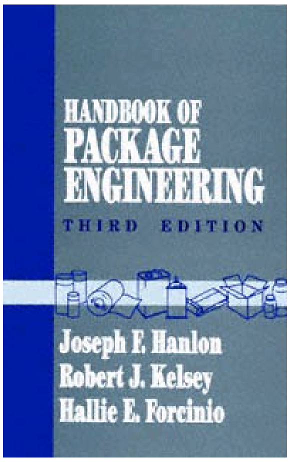
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PACKAGE
ENGINEERING
THIRD EDITION
Joseph F. Hanlon
Robert J. Kelsey
Hallie E. Forcinio

Handbook of Package Engineering

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Handbook of Package Engineering

Third Edition

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Preface

In every field of science and engineering, there has to be an up-to-date handbook to provide specialists with a broad collection of technical details about the individual elements of the field that no one today can be expected to remember forever. Nowhere is this more true than in packaging, where the types and variations of packaging materials and containers have multiplied in staggering numbers since this book was first published in 1973 and updated in 1983 by its original author, Joseph F. Hanlon, who passed away in 1996 as this new edition was being prepared.

A simple update was no longer capable of providing packaging engineers with the best data on this rapidly expanding and changing field. As the new co-author, I spent a year before even hitting a computer key in delving through every sentence in the original volume and starting the search for new information that would correct out-of-date materials and practices and expand each section. This task continued until the last chapter was turned over to the publisher, so that important current developments would be available in the new edition.

In mid-stream, I realized that the magnitude of this task was too big for one researcher and writer, hence, the addition of a third co-author, Hallie Forcinio, without whom this new volume would not yet exist.

It became a major research project involving a host of people from associations, packaging suppliers, and end users throughout the four-plus years that have elapsed since receipt from the publisher of a computerized copy of the original book.

Readers familiar with the earlier editions will find that almost everything has changed. For example, vast innovations have occurred in the field of plastics and the containers and films made from them. The chapter devoted to these topics has more than doubled in length.

But even “standard” container forms are now technically different in many constructions, materials, and uses. Printing methods are more varied. Even most of the adhesives used in package construction are barely recognizable.

This is not a book about packaging machinery, but the interaction between packages and the filling/loading/handling equipment is of critical importance to the success of a packaging operation. Therefore, the machinery chapter has been expanded to include information on how to select machines and containers that work together to create an effective production system.

The laws and regulations that govern packaging procedures have grown increasingly complex and are explained in greater depth in a considerably expanded Chapter 20.

Environmentalism and its criticism of packaging scarcely existed when this book was first published, so a new chapter on these issues has been added. Its goal is to help packaging professionals develop environmentally sensitive containers and practices that, as far as possible, are more acceptable in this new world of conservation.

The people who actively supplied us with information, illustrations, and suggestions about where we could find additional data for this edition are listed in the Acknowledgements section, both to thank them for their selfless help and to show readers the number of people it takes, today, to pull together a handbook in this broad field.

ROBERT J. KELSEY

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Chapter 1—
Elements of Packaging

Introduction

Our economy is a complex structure with many facets, and the importance of packaging within this system is becoming increasingly significant. Current methods of preserving and distributing goods are such an essential part of our way of life that we take them for granted and hardly realize how much modern packaging techniques contribute to our standard of living.

Some idea of the magnitude of packaging's share in our economy is revealed by the fact that expenditures for packaging materials, containers, converting, and printing now exceed $83 billion per year in this country, with another $3.8 billion for packaging machinery (see Table 1.1). Annual expenditures worldwide are said to measure more than $238 billion [1].

Packaging, along with better transportation, has made it possible to centralize production facilities into areas where raw materials are concentrated and, therefore, take advantage of the economies of large-scale operations. Protective packaging then enables products to be transported to areas of dense population and major consumption. The product and the package have become so interdependent that we cannot consider one without the other.

The functions of a package are basically to protect, contain, carry, and dispense a product. Leaves, shells and the skins of animals served as packages for these purposes for primitive man. As time went on, other requirements were added, such as to preserve and to measure, and later to communicate and to display. We have now entered an era in which the package is called upon to motivate, promote, glamorize, and sometimes to build up or even disguise the contents.

TABLE 1.1. Value of U.S. Packaging Material Shipments in 1995.

Packaging Material	Value in Billions of Dollars
Paperboard & Paper	$31.2
Flexible Packaging	$14.2
Metal Cans/Drums	$13.8
Plastic Packaging	$11.6
Other	$7.4
Glass Containers	$ 5.1
TOTAL	$83.3

Includes closures, crowns and flexible tubes.

Data sources: PaineWebber, U.S. Dept. of Commerce, Rauch Associates

Source: From *Packaging Strategies* newsletter, February 15, 1995. Copyright 1995. Reprinted by permission from Packaging Strategies, Inc., West Chester, Pennsylvania.

To transfer a particular product, for example, a powder, from the place of manufacture to the point of use requires some kind of container not only to carry it, but also to protect it from external damage. If the product is perishable and will not be consumed immediately, it must be preserved by some appropriate process. Now, the package also serves as a barrier to separate the preserved item from outside contamination and spoilage.

At the manufacturing stage the product is usually in a bulk tank of some type, and it becomes necessary to subdivide it into more convenient units for transportation and handling to the wholesale and retail level. These steps may require still greater reduction in the size and number of units to accommodate trade demands (see Figure 1.1).

The sugar barrel and the butter tub were once the standard packages in the grocery trade. Most of the subdividing in those days was done at the retail level.

This method has given way to a system that includes a reduction in the size of the units produced at the manufacturing plant. The product is put into small boxes or bottles, which are then gathered into groups by means of chipboard packers or by film or paper bundling. These "distributor packs" or "shelf stockers" are further overpacked in corrugated case lots for shipment to distribution warehouses or directly to retailers or, in the case of industrial products, to the end users.

Thus, reducing the size of the unit to be handled at each stage along the way is made much easier, and the function of carrying is accomplished more effectively toward the point of ultimate use. In the hands of the consumer, the product may not be used all at once. Therefore the consumer must often be able to remove a portion of the product without destroying the container, so that the remainder can be kept safely for future use. The convenient dispensing of contents is an important function of the package, along with containing and carrying.

In many cases, such breakdown packaging has provided the opportunity to standardize the quantity of material in a package to obviate dealing with arbitrary amounts of goods. The packaging of butter and milk are examples of uniform systems whereby an item can be bought in even pound or exact quart containers. In these cases, the package becomes a measuring device in addition to its other functions.

The opportunity to identify package contents by the shape, color, and decoration was realized a long time ago and has been exploited to an ever-increasing degree until it has now become one of the prime functions of the package.

Symbols, trademarks, slogans, and other devices are used to help the manufacturer communicate with the consumer. Copy may also take the form of instructions, warnings, guarantees, and specifications. This is especially effec-

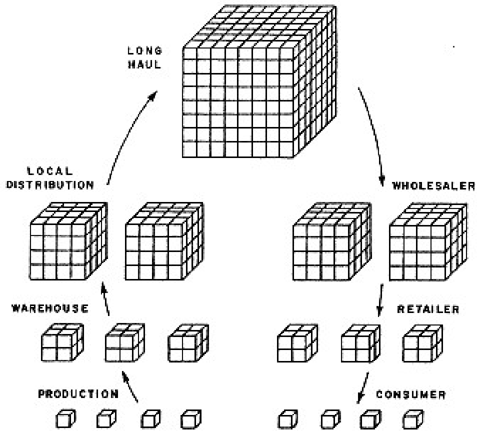

Figure 1.1.
The distribution challenge starts with assembly and packaging of individual product elements. These are collated into larger unit loads for transport and storage. If distributors are involved, smaller quantities must be broken out along the way. In the end, though, the final element of purchase generally still is the individual product unit. Throughout this taxing cycle, specialized packaging must contain, guard, and identify the product at each stage.

tive because the message remains with the product through all stages of transportation, distribution, and consumption and is accessible whenever needed.

Trademarks on packages have been very useful in promoting sales to consumers. By “guaranteeing” consistent quality, they have been the means of developing a loyalty among purchasers for brands such as Campbell's soups, Dole's pineapple products and Heinz pickles. This could not have been accomplished when butter was sold from a tub and sugar from a barrel. It became possible only with the advent of unit packaging. As the package and its contents move through commerce, the message on its surface is seen by a great number of people.

Exposing the message on the package to the passing traffic is a very effective and economical form of advertising, and we are constantly learning better ways to take advantage of this packaging-display value to attract attention.

This is particularly important since self-selection of packaged goods is continuing its spread from neighborhood commodity markets to the vast discount, club, and warehouse stores, which carry even costly products. Today, the package is the sales clerk.

As a result, designers have increasingly glamorized the package with the use of foils, fabrics, striking decorations, rich embossing techniques, and exotic closures, which create an illusion of something very precious. Packaging also is becoming increasingly interactive. Tiny light-, motion- or switch-activated electronic components now make it possible for packages to blink lights or play audio messages for consumers.

Any discussion of packaging inevitably brings up a consideration of aesthetics and the part that appearance plays in the design. Since the effect that the visual impact of a package has on the beholder is only just beginning to be understood, it is difficult to establish criteria for artistic design as it applies to packaging.

Much has been written on the psychology of color, copy, and composition, as well as on the styling of containers. Creative design has accomplished some interesting results. While some conclusions can be drawn from these experiences, designers nevertheless tend to copy one another's successful creations, and this usually leads to fashions and fads instead of to any real effort to satisfy the needs of the trade. Thus, we have packages of cake mix that all try to incorporate “appetite appeal” with a color photograph of a finished cake from which a slice has been removed.

This generally results in a sameness that cancels out any competitive advantage that one brand might have. For example, many liquid dishwashing detergents have been put into narrow-waist plastic bottles with paper labels and differ very little from one another on the retail shelf. However, a few pioneers among the designers are making good use of graphic processes and structural styling, and their approach to marketing problems is worthy of careful study.

The matter of style in packaging deserves some explanation. While it is closely associated with aesthetics and is a term that is sometimes applied to periods of design such as baroque, Bauhaus, sculptured, streamlined, or rococo, our use of the term is somewhat different. What is meant by styling in this text is the total impression of the shape, color, texture, and typography of the package. Thus, it is possible to have a design that is obviously feminine, delicate, and romantic for a cosmetic item, or in another case, a package that is bold, rugged, and strongly masculine for a product in the hardware field.

In the first case, the colors might be pastel shades, the typography might be a dainty script style, and the structure might be delicate and frilly. On the other hand, to appeal to men, a product would more likely be sturdy-looking with strong dark colors and bold printing (see Figure 1.2).

The proper choice of design elements for a package can evoke a feeling of nostalgia, whet the appetite, or create an atmosphere of opulence and luxury by the way these components are handled. It is this projection of a feeling about the product inside that gives packaging some of its power to promote sales and increase profits.

In contrast, it can be a deterrent to sales if it is not handled properly. In this image building through design, it is necessary to stay within certain boundaries: not to limit ingenuity and creativeness, necessarily, but to keep within the recognizable area of design that is associated with a particular class of trade.

The point here is that a package for a certain product should look as if it belongs to that kind of product. It would be completely out of character, for

Figure 1.2.
The choice of typeface can help set the mood of a package. Different styles connote various impressions in the mind of the viewer, and a font usually can be found to suggest the precise shade of meaning desired.

example, to put floor wax into a footed crystal bottle with a gold tassel and an exotic closure, just as it would be wrong to have an expensive perfume packaged in an amber prescription bottle. The aesthetic design of a package should be used to dress up or enhance the product it contains, but it must not be used to mislead or deceive the purchaser. The power of a package design to attract attention and encourage sales should not be abused at the risk of alienating the buying public, or bringing the forces of the government against the packaging community.

Fields of Packaging

Packaging has many faces, depending on the position of a person in the field. In its more familiar forms, it is the box on the grocer's shelf and the wrapper on a candy bar. It also can be the crate around a machine or a bulk container for chemicals.

It is an art, a science, and engineering. It is materials and machinery. It is protection, promotion, law, logistics, manufacturing, and materials handling—all rolled into one. Because it is different things to different people, it is a difficult concept to define. Nevertheless, we shall proceed to dissect packaging along certain arbitrary lines in order to study its composition.

There are four broad packaging categories that require different technologies and talents for their accomplishment: (1) consumer, (2) institutional, (3) industrial, and (4) military.

Consumer packaging generally is concerned with small items produced in large numbers and is highly decorated to provide a self-selling function. This field encompasses a very wide range of products, the largest volume of which are foods and nonprescription (over-the-counter) drugs. But it also includes an enormous variety of other products used in and around the home for living, personal hygiene, and recreational needs. Packaging for such products utilizes virtually every small-volume container and material form and generally is sized for individuals or small family groups.

Institutional packages generally hold a larger quantity of products that can range from office supplies and cleaning agents to foods and beverages. Decoration is simpler, although growing competition has created a trend toward more eye-catching labels. Packaging includes film wraps, large bottles, jugs, pails, and drums, as well as moderately sized corrugated boxes and industrial bags.

Industrial packaging starts with heavy wooden crates, big bags, conventional corrugated boxes, large drums, and glass carboys. But today, this field also includes pallet boxes of heavy multiwall corrugated and flexible intermediate bulk containers, which hold several thousand pounds of product.

There also are molded plastic tanks with built-in legs and heavy-film-lined corrugated or wooden pallet structures for liquids such as aseptically packaged food ingredients. Decoration of industrial packages has historically been limited to identification and instructions. However, vigorous competition in some fields has led to container coloring and labeling ideas borrowed from the retail sector.

Military packaging is a highly specialized type of protective packaging in which all elements—most particularly product identification and inspection procedures—have been defined by the government and documented in intricate detail. There are several levels of protective packaging, but economics have caused many military goods and items purchased for the federal government to be downgraded to consumer-weight packaging.

While these descriptions are fairly simple, reality is not as clear-cut. For example, items intended for select classes of trade, such as veterinarians and beauty operators would be classified as institutional packages, but could utilize packaging ideas from either the medical/surgical or retail sectors. Toiletries and cosmetics use very upscale packaging compared to most other consumer goods. Hazardous products are subject to a special set of rules, which are as defined and restrictive as those for military items. Such products require the attention of specialized structural and graphic designers.

Whatever the product, production-line effectiveness also is a critical requirement and an engineering specialist will be necessary to evaluate and select appropriate equipment and ensure efficient, consistent operation.

One thing is for sure, it is not possible for any individual to be skilled in all product, package, or equipment types. As a result, most situations require the combined talents of a team of experts often from both inside and outside the company.

For some projects, consultants commissioned to work on the assignment and representatives from packaging material and equipment suppliers are used to supplement the efforts of staff specialists.

State of the Art

For years packaging development relied greatly on trial-and-error methods. However, with establishment of university programs and departments in packaging science and engineering, and with increasing interest from and work by established standards bodies, packaging developments have now taken a more reliable course.

As a result, the amount of technology available today is enormous and continues to grow at a rapid rate. In the past, workers in the field were very dependent on a few periodicals, seminars, and trade shows to keep abreast of developments. Now there are more periodicals and a great number of seminars and trade shows—both industry and multi-industry and either international, national, or regional in scope. In addition, there is a growing amount of comprehensive literature available to serious students of packaging technology and engineering.

Since packaging accounts for an important share of the cost of goods (see Table 1.2), it follows that workers with responsibility for making recommendations and influencing decisions about packaging need all the knowledge and skill they can muster. Further, they should approach their tasks with an open mind and a broad perspective if they are to take full advantage of the great variety of materials and techniques that are available. To become preoccupied with routine solutions to problems is to miss opportunities that exist for truly great accomplishments in a dynamic and exciting field.

There is no question that packaging is multidisciplinary and borrows from many fields of science and engineering—including organic and inorganic chemistry; metallurgy; mechanical, industrial, chemical, civil, and electronic engineering; nuclear science; physics; mathematics; microbiology; toxicology; art and design; and more (see Figure 1.3).

However, the relevant data and technology of these established fields are now being extracted and transformed into a body of knowledge that relates specifically to packaging. In turn, industries that employ packaging—such as pharmaceuticals, food technology, electronics, petroleum products, ware-

TABLE 1.2. Food Packaging Proportion of the Food Dollar in 1994.

Labor	$0.37
Farm Value	0.21
Packaging	0.08
Other Costs	0.08
Intercity Transport	0.045
Advertising	0.04
Depreciation	0.035
Rent	0.035
Fuels & Electricity	0.035
Pre-tax Profits	0.03
Interest (Net)	0.025
Repairs	0.015
TOTAL	$1.00

Other costs include property taxes and insurance, accounting and professional services, promotion, bad debts and many miscellaneous items.

Source: U.S. Department of Agriculture, Washington, D.C.

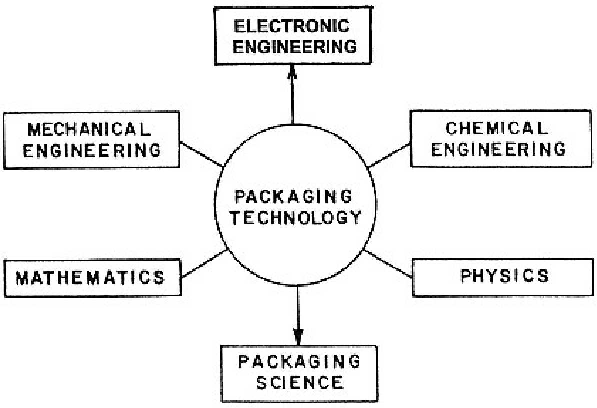

Figure 1.4.
Older disciplines are contributing rules and data to what will become a new multidisciplinary packaging science and engineering technology

housing, transportation, and others—are extracting principles that answer their specific needs.

Examples are numerous. Radiation treatment is now decreasing spoilage in transit for fresh foods and creating greater protection from tenacious pathogenic microorganisms. Electronic and optical principles have been wedded to automatic quality-control instrumentation to ensure the correctness of labels on pharmaceutical products.

The age-old problem of effectively moving large amounts of packaged goods from the point of manufacture to use is now receiving increasing attention. One method is containerization, which increasingly is used on land and sea and in the air for the transportation of bulk quantities (see Figure 1.4). These larger quantities, in turn, are broken down into smaller amounts desired by distributors, retailers, and the final customers. While effective break-bulk techniques are widely used, bulk packaging has assumed new importance with the advent of warehouse and club stores, where no-frills decor and large quantities mean lower prices.

Demands for consumer convenience are being met by increased use of vending machines in locations close to consumer habitation or travel and a growing variety of prepackaged meals and meal ingredients. Supermarkets and other mass merchandisers are scanning bar-coded merchandise to cut

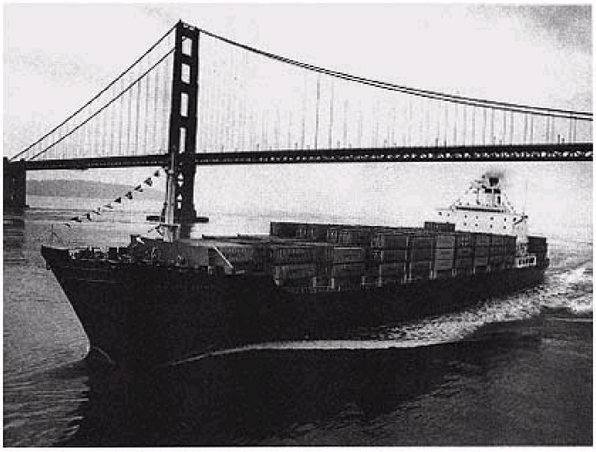

Figure 1.4.
A containership can move goods at a lower cost and with less damage than conventional methods of handling, while improving transit times up to 50 percent. The containers are made in various standard sizes, most commonly 20 or 40 by 8 by 8 feet. Loaded at the shipper's warehouse, they are transported by rail or truck to the dock, put aboard the ship, and delivered to the consignee's warehouse, without ever being unpacked. Damage is reduced 90 percent and pilferage is nearly eliminated, cutting insurance rates. *(Source:* Sea-Land Service, Inc., Charlotte, North Carolina.)

checkout time and reduce labor requirements and are moving toward electronic ordering, picking, and billing to further minimize handling time and effort.

Similar problems and a continuing search for solutions exist with institutional items and some industrial products. But in all of these distribution areas, the development of specialized packaging increases convenience and reduces overall costs.

In this process of packaging, storage, transportation, and display, the combined retail and distribution containers must contain, protect, identify, and describe the product to the satisfaction of production-packaging personnel, warehousers, shippers, distributors, retailers, and consumers. It must meet the cost requirements of purchasing, plus the display and advertising appeal required by sales and marketing. Finally, it must meet user requirements for instruction, storage, and dispensing. In varying degrees, these requirements apply to all products—retail, institutional, industrial, and military.

The Newest Challenge

Technologically, anyone would think the above functions should suffice. However, the boon of packaging carries with it the bane of its omnipresence and ultimate need for disposal.

Starting in the late 1960s, the public began to couple this fact to the increasing cost of municipal waste disposal. Others with broader viewpoints noted the fact that much packaging derives from materials of finite availability. A cry went up that packaging should be eliminated, reduced, reused; that some container materials were friendly to the environment; others unacceptable.

States passed legislation governing the types of acceptable materials and restricting disposal. Recycling equipment, procedures, and collection organizations were developed. Facts began to replace fiction—and then the recession of 1974 ended it all, except for the good work of Keep America Beautiful with its continuing and successful program to combat littering.

What goes around, comes around, though, and in the mid-1980s the cry rose again, this time coinciding with a national concern over the safety of our land, water, and air in an environment of increasing pollution. Currently, the country is still going through the initial stages of choosing and condemning materials and passing impractical and restrictive regulations. Nonetheless, positive steps have been taken toward reducing the amount of packaging used, reusing containers and materials where practical, and recycling household packaging as well as some industrial and transport packaging.

Development of sensible and economic reuse and recycling techniques is a desirable technological development for packaging. Since some packaging materials, such as metals and plastics, are derived from finite, relatively expensive resources, it seems to many that landfill disposal is wasteful. There are also strong feelings among some citizens and regulators that the incineration of plastics to create power is a less than ideal alternative to reuse. Details on regulations for environmental packaging and trends in technical development can be found in Chapters 20 and 21, respectively.

The Packaging Function

Because packaging has roots in nearly all the different departments of a manufacturing organization, its proper placement on the management chart is not as clear-cut as it might be, and management choice is often personal rather than logical. The degree of success or failure of the packaging function is certainly influenced by the line of authority that its location brings with it, and even more by the personality of the people involved and the support it receives from upper management.

In the consumer goods field, packaging design and development are related to manufacturing as well as to marketing. Procurement, processing, warehousing, and distribution operations also are tied to it.

Since by its nature it is essentially a staff operation, packaging container and machinery development often are associated with the engineering department in one or another of its various forms. Depending on the personality and orientation of the company, this could be equipment, plant, process, design, or industrial engineering. Rarely does packaging have sufficient status to stand by itself alongside other manufacturing functions.

A case can be made for placing packaging in other areas, such as purchasing, research and development, marketing, or distribution. However, the ideal is that of a separate department with lines of communication to the other corporate departments and with direct responsibility to a top officer in the company. There are few instances, today, where this is the case, but it is likely that the recognition of packaging will grow along with its corporate prestige.

Consultants

Because of the above factors, there is a growing body of experts within the packaging field that function as professional consultants. Most of these now belong to the Consultants Council of the Institute of Packaging Professionals (IoPP), Herndon, Virginia. Their talents are quite varied and, with proper selection, they can give advice on just about any aspect of packaging. Fees range from about $85–$190 per hour and average about $100 per hour. However, quotes frequently are prepared on a per-project basis.

There also are some advertising agencies and market research organizations that work on packaging problems with varying degrees of proficiency. A firm that specializes in packaging as a coordinated product of art, science, and technology with no special interest in any particular packaging form or material is most likely to provide the most satisfactory service to its clients. The fees sometimes run high, but when such consultants are carefully chosen and used intelligently, the results are well worth the price.

Proper use of a consultant requires a clear definition of the problem and as much supporting data as can be made available by the client. When hiring a consultant, it is wise at the outset to arrive at a clear understanding as to the scope of the project, schedule of delivery, rate of payment for various stages, form and design of the information and/or designs to be delivered, assignment of patents, secrecy, and conflict with competitive accounts.

Suppliers

The service of suppliers in developing and producing packaging components is an important part of launching any new item or improving an existing one. Suppliers should be very knowledgeable concerning their specific materials, container, or equipment, because they usually have experience with a multitude of packaging projects. This can enable them to be very practical in their recommendations. Some leading packaging converters are shown in Tables 1.3 and 1.4.

The quality of work will vary among different companies, and most vendors tend to specialize in a particular type of packaging or packaging equipment and, in some cases, even specific industries. Some materials and container suppliers have excellent art staffs and are capable of top-notch styling. Some machinery suppliers are very knowledgeable about specific product fields. But all suppliers need the guidance of and close liaison with their customers for best results.

A good working relationship with suppliers must include good communication. This means adequate specifications as well as agreeable acceptance and rejection standards. The importance of a clear understanding between vendor and customer before any commitments are made, cannot be overemphasized. Such things as delivery dates and penalties, limits on overruns and underruns, cancellation charges, ownership of tools, secrecy from competition, and protection from patent suits should all be put in writing to avoid later disagreements.

Contract Packagers

Modern industry is an unstable mixture of markets, materials, and techniques that requires a certain amount of flexibility to be successful. One source of the necessary operating know-how and production facilities is the contract packager.

TABLE 1.3. Leading Packaging Suppliers in the United States.

American National Can Co.
Ball Corp.
Crown Cork & Seal Co. Inc./Carnaud Metal Box
International Paper
Jefferson Smurfit Corp.
Owens-Illinois, Inc.
Printpack, Inc.
Reynolds Metals Co.
Sonoco Products Co.
Stone Container Corp.
Tenneco Packaging
Union Camp Corp.
Weyerhaeuser Co.

TABLE 1.4. Leading Packaging Suppliers Worldwide

Company	Global Packaging Sales (in billions)	U.S. HQ/Branch
Crown Cork & Seal/CMB	$10.0	U.S. HQ
Tetra-Laval	6.1	Tetra Pak Inc.
Toyan Seikan	5.5	
Pechiney	5.4	Am. National Can
Stone Container Corp.	4.3	U.S. HQ
Tenneco Packaging	4.0	U.S. HQ
Viag	3.8	
Saint-Gobain	3.7	Ball-Foster Forbes
Owens-Illinois Inc.	3.6	U.S. HQ
International Paper	3.4	U.S. HQ
Jefferson Smurfit	2.6	Jeff. Smurfit Corp.
Vitro	2.5	
Ball Corp.	2.5	U.S. HQ
Sonoco Products Co.	2.3	U.S. HQ
Amcor	2.3	
Van Leer	2.2	Van Leer
Alcan	2.2	Alcan Foil Products

Source: Adapted from *Packaging Strategies,* November 30, 1995, and *European Packaging 1995/96 Volume II* from Pira International, Leatherhead, United Kingdom, 1995.

Nearly all companies, from the smallest to the largest, avail themselves of such "satellite" manufacturing plants. Today, a typical job packager will limit itself to a few packaging operations in which it excels—or in some cases, even to a certain type of product.

A packager of pharmaceuticals, for example, will strictly avoid handling pesticides in the same plant for fear of contamination. It may handle aerosols only, which require a large capital investment in equipment and very specialized packaging knowledge. Products such as lipsticks, nail enamel, and bath soaps, which require special skills in color matching and fragrance blending, are difficult to formulate and often best left in the hands of independent product and packaging specialists. Such specialization is common and makes it necessary to choose carefully among the different copackers. A directory is available from the Contract Packagers Association, Herndon, Virginia. Many also advertise in the classified sections of packaging or industry-specific trade magazines.

With the growth of giant marketing chains that are now demanding a strong voice in how products are packaged and combined for special deals, a new brand of contract packager is emerging. This "special packager" generally guarantees it will handle anything the chain stores throw at it. The operations are usually a series of manual steps, paced by semiautomatic machines.

Since primary packagers generally have dedicated high-speed lines, which are not designed to handle such abrupt changes in packaging configuration, the special packagers with their more flexible operations appear to be the answer. But control of costs—and, thus, effectiveness of such operations—is highly dependent on the cleverness and efficiency of the staff in creating very flexible production-packaging lines and equally versatile employees. Therefore, selection of such special packagers must be done with even greater care.

Contract packaging can supplement an in-house operation or be the sole source of packaged products. It is one way to start up a new product with minimum risk.

Once a product is established, or at least shows potential for growth, it may be feasible to bring it in-house. This may offer greater control and an opportunity for cost improvement through high-speed packaging equipment and purchasing power.

Preparation for a Packaging Career

Although the education and experience needed by a packaging technologist or engineer will depend on the particular employer, the range of skills and talents required extends into many branches of science and technology.

A student desiring a career in packaging would do well to get the broadest possible foundation at the outset, and then specialize as the job requires it, while expanding the wide perspective.

Certain disciplines are basic to almost any branch of packaging, so the education of a packaging professional should include these fundamentals: mechanical and electronic engineering, inorganic and organic chemistry, materials science, physics, mathematics, and economics. All of these are applicable in some degree to every packaging problem. Optional subjects might include marketing, graphics, industrial engineering, communications (writing), and microbiology.

A number of universities and colleges have added packaging programs to their curricula. Schools offering academic degrees in packaging include Indiana State University, Clemson University, Rochester Institute of Technology, and Michigan State University, which recently established the first Ph.D. program in packaging.

California Polytechnic State University, Rutgers-The State University of New Jersey, University of Illinois at Urbana-Champaign, Texas A&M University, Cornell University, San Jose State University, University of Missouri-Rolla, and University of Wisconsin-Stout offer degrees in related subjects with specialization in packaging.

Other schools with more limited programs in this field include Sinclair Community College, Pratt Institute, School of Military Packaging Technology, and Fashion Institute of Technology.

IoPP's annual *Who's Who and What's What in Packaging* directory lists schools offering packaging courses.

For continuing education in the packaging field, IoPP and some other trade and technical associations sponsor seminars on a variety of technical packaging and machinery subjects targeted for both new and experienced professionals.

Publication of technical books related to packaging also has increased in recent years. Many titles are available from IoPP's Bookstore. The seminars and books can be a lifesaver for technologists with backgrounds in other disciplines who are suddenly transferred to packaging operations.

The Packaging Professional

A packaging professional should approach the job with a good knowledge of the materials and processes used in all branches of the industry, and with a high degree of skill built up by experience with the different materials—glass, metal, paper, and plastics. In addition, this person must exercise ingenuity in adapting these materials to solve the task at hand. A technologist also must be armed with personal characteristics and acquired knowledge not readily obtained from seminars or books.

Ethics

For personal and corporate well-being, packaging specialists should know and practice a standard of behavior that fulfills their obligations to the profession, to the business, and to society in general.

They will not design nor endorse packages that are deceptive or misleading, even though they may be within the legal limits. A package should be honest and forthright, and must not deliberately give an impression of containing or delivering something that is not there. This is not to say that it should not enhance the product or make it more attractive. Certainly this is an important function of packaging. But fake bottoms, excess packing, and similar tricks to fool the consumer should be scrupulously avoided.

The packaging specialist will serve an employer or client with devotion and loyalty. He or she will be honest in their estimates and sincere in advice and counsel.

Padding or overdesign with intentions of making dramatic savings at a later date is, obviously, an unethical practice. Recommendations must be offered with all the pertinent data and without bias or prejudice. A good technologist cooperates with representatives of all other company departments and with any and all experts assisting with the project.

Such confidential information as designs, processes, plans, and intentions should be held secret except with the express permission of the employer or client. Any knowledge of methods and techniques obtained in the course of a project will be used only for the benefit of that project.

A packaging professional will not accept gifts or gratuities intended to influence recommendations or specifications. He/she will avoid having vendors spend large amounts of time or money on speculative presentations. He/she will not ask for samples or quotations from a supplier if no order is likely to result, unless the vendor is made aware of the circumstances.

Every effort will be made to pay for design and engineering samples, and those companies that charge for these services will be encouraged and will not be discriminated against. Credit for ideas and designs will be given where due, and the packaging specialist will not take credit for work that is not his/her own.

The matter of ethics in dealing with suppliers should be taken very seriously for the benefit of all concerned. Any submission of packaging or machinery ideas, designs, samples, or artwork by a vendor to a packager should be treated as confidential. Unless full payment is made to the vendor on a mutually satisfactory basis, the customer does not have the moral right to disclose these designs to a rival supplier. Nor should the customer use these ideas unless the submitting company is given the opportunity to recover its development expenses through orders of sufficient size to include these costs.

The reverse is true, as well. Suppliers have a moral obligation to treat information from a customer on products, container designs, and production-packaging operations as completely confidential.

Another area of responsibility is to encourage and help train novices in the field. In relations with fellow workers, he/she will cooperate freely in the exchange of knowledge and will give advice and counsel generously when requested. He/she will not injure the reputation or prospects of another packaging specialist, but if there is proof of unethical practices, the proper authorities will be advised. He/she will contribute time, effort, and funds to further the progress of packaging technology, through publications and membership in professional societies. He/she will participate actively in seminars and other educational programs to share knowledge and experience with other members of the profession.

Successful Package Design

Consider all five senses when designing a package, not merely the visual impact. The rustle of silk, the pop of a cork, the clink of glassware all add to the enjoyment of certain products. Perfumed ink, for example, can give the product subliminal appeal to the potential purchaser. It is often possible to appeal to the sense of touch by choosing a material with a special texture, or by embossing it or forming it to make the package feel attractive.

We have only begun to explore the possibilities for putting more sales appeal in packaging, and we may be missing opportunities for creativity by slavishly copying packages that are already on the market.

The size and shape of a package can be important elements of design for several reasons. The value of a product may be measured subconsciously by the impression of its size, and in a competitive situation, the consumer will often reach for the larger of two rival brands. However, space limitations in the store and in the home also must be considered. If a drug product does not fit in a medicine cabinet or a box of cereal is too large for a kitchen cabinet, this can have an adverse effect on repeat sales.

In some cases, the package actually becomes a part of the product, and in this way serves to augment and enhance its usefulness. Containers and closures that measure, mix, or dispense the product can, in a sense, be considered an integral part of the product concept. As an example, hair spray without the valve-container-propellant system would not be nearly so popular as it has become. Popcorn in a disposable cooking utensil, charcoal for a barbecue that uses the container as a starter, and frozen dinners in a serving tray are all innovations that have won enthusiastic acceptance by consumers.

A radical design concept is more likely to bring outstanding success, by its very nature, than is a conventional solution. Therefore the extra effort that is required to brush aside obvious answers and probe deeper into the requirements of the package will usually yield great rewards.

The successful designer must constantly ask what, when, and how on every aspect of the project and explore uncharted avenues to find those new ideas that generally lurk close at hand just waiting to be uncovered.

The design of a package is not isolated, but part of a larger effort to carry the product to its end use in a successful manner. As such, the package must fit into a manufacturing-packaging-storage-distribution-marketing system and contribute to the effective operation of each of the above segments.

Far too often, a package is designed without any consideration for its ability to run on existing packaging equipment at required speeds and efficiencies. Product and shipping containers are still designed that do not meet the strength requirements for warehouse storage, where economics are dictating ever-higher stacking of pallets.

Truck, rail, and ship transportation, each with their special patterns of vibration, roll, and sway are hazardous enough for goods. But, highways and railroad beds also deteriorate, increasing the forces to which products and packages are subjected.

Faster delivery methods of the overnight variety and less-than-truckload quantities to meet just-in-time delivery schedules are rougher than full-truckload and palletized unit-load configurations and must be accounted for in packaging design.

Marketing measures are changing, too. Environmental considerations, increasingly backed by state regulations that vary from one to another, demand use of recycled materials drawn from post-consumer sources in addition to and in preference of post-manufacturing waste.

The growth of larger and more powerful retail store chains, which gain their knowledge of what consumers want by computer analysis of bar-code purchasing data and detailed surveys, now tell product packagers what packaging designs and product combinations they will accept. They get their way, too, since product competition is at a fierce high and the volumes turned over by such chain stores are impressively enormous.

Package design also depends greatly on the quantities involved. The low-volume item, for example, will not justify special molds and sophisticated equipment, but must utilize stock containers and semiautomatic or manual assembly operations.

This is not to say that this type of design assignment is any easier; on the contrary, the limitations of the low volume may very well tax the knowledge and skill of the developer far more than the high-volume package, which generally is well budgeted, permits thorough investigation, and draws eager help from big vendors. The physical needs of these disparate products may be equally rigid, but the opportunities for design will be quite different.

Compare the design of a high-volume beverage bottle, for example, with that of a chemical intermediate of very limited application. Costs are critical in the first case and risks of some container failure can be accepted if justified on an economic basis. The chemical product with a smaller budget demands more ingenuity to adapt existing materials. Over-design may often be warranted to prevent failures and loss of costly or dangerous product. Some idea of the cost put into a package is shown in Table 1.2.

Know Your Product

It may seem elementary to suggest that a thorough knowledge of the product is essential to successful package design. But, too often a packaging specialist does not learn all that is necessary before starting design work or equipment selection.

With tight development schedules, there is a temptation to jump ahead with partial information. But success depends upon complete data about the nature of the product, its competition, its utility for the user, marketing goals, and distribution methods.

The most critical requirement of a package is that it maintain its integrity under all conditions of storage, distribution, and end use. It must also protect the product in the above environments. Generally, it must meet regulatory requirements to inform the distributor and/or purchaser of its identity, content, weight, or volume and the location of its manufacture.

In the case of dangerous products, packages must state the nature of the hazard and methods to prevent or offset injuries from such hazards. For dangerous products that enter the home, the package closure must retard the efforts of children to gain access.

Packaging for OTC drug products must, by law, use means to indicate any attempt to enter the package before being purchased by the end user. Although not yet a statute, the same tamper evidence in containers is strongly advocated—and widely used—for food products.

Communicate

It may be trite to say that good communications should be maintained with all departments during the development of a new package structure, but nevertheless the statement is very true. The problem is not usually a lack of information; more often it is either an unwillingness to seek out the information or an ineptness on the part of the designer in not recognizing the practical requirements of mass production.

Professional package developers will measure their design against the needs of procurement, manufacturing, storage, shipment, and sales to be sure no potential trouble spots have been overlooked. Although a compromise may be necessary when various requirements conflict, a capable designer will try to make judgments in light of the facts.

Market Analysis

A clear understanding of the market segment that the package is expected to serve is necessary before a good design can be created. Whether the potential customer is male or female, young or old, rich or poor, urban or rural often will affect the type of design to be recommended. Merchandising methods, display techniques, and advertising support all will have an important influence on the final design.

The appearance of a package on a shelf may be quite different from the way it looks on the drawing board or on a client's desk. It is wise to view a new package in a trade situation surrounded by competing products before finalizing the design. There are a variety of commercial package designers and marketing research firms that can offer such a service.

If surrounding packages are all dark, or tall, or decorated in a similar way, it could be smart to choose a contrasting format to distinguish your product from competing brands. A word of caution, however, before adopting a design just to be different: If customers are accustomed to getting a product in a certain type of container, they may not accept a design too far removed from the expected size, shape, or color.

After all of these measures have been taken, the desires of the end-user—hardly less critical to success—must also be addressed. A well-designed package will cater to the needs of the purchaser. These may be psychological desires or practical applications; but whatever they are, the package designer must recognize and satisfy them. To be more specific, the design of the package must show at once the intended use, method of application, and promised results.

A container of talcum powder should not look as if it contains scouring powder, nor should face-cream jars resemble shoe-polish containers. It is sometimes possible, however, to upgrade a household product by borrowing some design elements from the cosmetic and toiletry field, without losing the product identity.

Style

Besides projecting its contents visually, a package also can convey the desired mood of the item. If dependability is one of the selling points, a design that uses old-fashioned elements may create an impression of proven efficacy. Toiletries and cosmetics require an aura of glamour and luxury, and often stress romantic themes. Pharmaceuticals can play up the scientific angle, soft goods can go high style, and food can emphasize the candlelight and silver mood of a dinner party (see Figure 1.2).

The shape of the package may be dictated by the available containers and the nature of the product, or it may offer opportunities for a variety of sizes and proportions, depending on quantities, physical requirements, and other factors.

Designers often are carried away by their desire to give the maximum size impression, and they fail to recognize the need for stability on the shelf and the space limitations in the home. Another fairly common error is to overlook the practical aspects of manufacturing and to create designs that cannot be run on the packaging line at a good speed because containers topple over, jam between the guide rails, or have an opening too small for filling.

Since there is a dark side to every picture, freedom of design has also, at times, been turned to using the package for purposes of deception, a practice to be rigorously avoided, since there are both state and federal laws governing this deception, too. Nevertheless, there are many examples in the marketplace that border on outright fraud. Packages for toys and games, for example, frequently are expanded out of all proportion to the physical requirements of the contents. Although the container serves as a display piece and is often treated like a billboard, this is scarcely an excuse for the overpackaging that is the rule and not the exception in this industry.

Further examples can easily be found, particularly in the fields of toiletries and cosmetics, confections and electronic consumer products. It is argued that custom makes such practices acceptable and that the customer is not deceived, but industry might do well to set standards in this area before legislators do it for them.

One justification for oversize packaging is pilferage, a growing problem in variety stores and other self-service outlets in Europe as well as the United States. Shortages have become a major retail expense with losses to shoplifting estimated at $9 billion in 1994 [2]. To make it harder to steal products, packagers often use oversize containers or big display cards.

However, the recent invention of ultra-small, thin sensors mounted in or on the product may make even this over-packaging passé. These sensors can serve as part of the label and are activated on entry to the store by the standard code-scanning device at the checkout register. Unless deactivated by being rescanned at the checkout, they trigger an alarm.

Copy

A promise should be implied in the main panel. The trade name and the subtitle or supporting phrases must appeal to the natural desires of the purchaser, either the need for sustenance and comfort or, better still, the desire for self-improvement, status, or indulgence for self or family.

The body of the text can expand on this theme and provide more specific information about the product and its usefulness. The sales message should not obscure the instructions for use and other pertinent data, however, and questions in the purchaser's mind must be anticipated and answered clearly and succinctly. Otherwise the package may be put back on the shelf and the sale missed.

The handling of the text on a package should be given careful study. The least amount of copy is nearly always the most effective, and particularly on the display panel of a package, the barest minimum of wording should be used. The more elements such as the trademark, description, catch phrases, quantity designation, and manufacturer's name, fighting for the attention of the viewer, the weaker the total effect.

It is important to have enough information on the package to answer the potential buyer's questions quickly and clearly. Too much “sell” often ruins otherwise informative copy, and this part of a package design requires careful handling.

Usually the time and effort that are needed to edit and arrange text and test it adequately are well spent. Store shelves are full of examples of packages where the wrong things are emphasized; surfaces are cluttered with nonessential trivia, and important information is lacking. A good testing program could have corrected most of these packaging errors, but a lack of humility among creative people often prevents them from seeking this type of assistance. Although the preparation of the copy for a package is beyond the scope of this book, a few details should be mentioned at this point.

There are also legal and regulatory copy requirements that vary by product, industry, and method of shipment (see Chapter 20, Laws and Regulations).

Product Liability

As shown in Table 1.5, there are a considerable number of injuries associated with packaging each year [3]. Glass containers produce jagged edges when they break, and metal cans sometimes have sharp edges. Providing handholes in a corrugated box to make it easier to carry might seem like good designing, but if the contents are so heavy that the paperboard might tear, then the result could be a lawsuit for smashed toes.

TABLE 1.5. Injuries Associated with Packaging.

Package Type	Estimated Number of Injuries
Metal Containers	105,879
Containers, Not Specified	65,636
Bottles/Jars, Not Specified	35,132
Glass Bottles/Jars, Not Specified	28,022
Glass Alcoholic Bev. Bottles	12,816
Glass Soft Drink Bottles	11,714
Aerosol Containers	5,644
Plastic Containers	3,479
Pressurized Containers, Nonaerosol	1,965

Estimated figures based upon emergency room visits recorded by the National Electronic Injury Surveillance System (NEISS) for the 1993 NEISS Product Summary Report from the National Injury Information Clearinghouse, U.S. Consumer Product Safety Commission, Washington, D. C.

To avoid costly litigation or unfavorable publicity, the package designer should be aware of any potential hazards and try to anticipate all possible ways in which a container could be misused. If the necessary protection cannot be built into the package, then suitable warnings should be printed in a prominent place.

Strict liability law in most states requires that "the manufacturer refrain from placing in the stream of trade a product in an unreasonably dangerous, defective condition, or to refrain from selling a nondefective unreasonably dangerous product without adequate warnings." This principle is supported at the federal level by the Consumer Product Safety Commission, Bethesda, Maryland (see Chapter 20, Laws and Regulations).

Since 1936 these laws have been increasingly liberal in allowing consumers to recover against all links in the production and distribution chain. The consumer can now sue the manufacturer, assembler, carrier, wholesaler, and retailer. To avoid these problems as much as possible, a manufacturer must keep good records to show that industry standards and government regulations have been followed, and that proper quality control methods were used.

In some industries such as foods and drugs, records of defects and failures are required to be maintained for several years. These may come to the attention of opposing lawyers in a discovery process. Marking a memo "Confidential" will not protect it from being produced in the discovery process. Therefore, the avoidance of defects and failures is a critical quality control objective.

Export Considerations

If a package is intended for use outside the country of origin, there is a whole host of special considerations.

As might be expected, the hazards of transportation are generally much greater. In some cases the use of slings to move goods on and off ships puts special strains on packages, and in some seaports, cargoes must be transferred to lighters to be brought to dockside. Moreover, considerable hand labor is used to load and unload ships, and this brings about special problems of damage and pilferage.

The usual practice is to make packages for this type of service one-and-a-half to two times stronger. Single-wall domestic corrugated boxes, for example, often require double or triple walls for export use. Wooden crates may be substituted for corrugated, and textile bags will sometimes replace multiwall paper bags, or the latter may be increased in thickness by at least two extra plies of paper. Packing fragile goods in 20- and 40-ft (6- and 12-m) aluminum containers is a good practice when these can be handled in the destination port.

Copy and graphics become more complex for export due to differing laws, customs, and traditions. In foreign markets, the wrong choice of words, illustrations, colors, symbols, and numbers can be pitfalls for the uninitiated package designer. For example, certain words can become completely unacceptable when translated into another language. Illustrations of dogs, pigs, and scantily clad women should be avoided in Islamic countries. Triangles are perceived negatively in Taiwan, Hong Kong, and Korea. Four is considered unlucky in Japan.

Colors can be especially significant. White, for example, is the color of death in Japan and Korea, but represents purity in many Western countries. Purple has negative connotations in Mexico and Brazil. Green is associated with toiletries and cosmetics in France, Sweden, and the Netherlands, but should be avoided in Egypt where it has nationalistic overtones. Black is anything but chic in Egypt, where it is associated with evil [4]. Gold, which is upscale in many countries, is down-market in Japan.

Color combinations also should be researched carefully. Black and saffron, for example, is the color of hell in Pakistan [5]. Blue and white should be avoided in Hong Kong, Arab countries, and Sweden but mean money in China [6].

Design for export is a highly specialized area, and the best advice is to move cautiously and to seek help from people with firsthand knowledge of the areas.

Vending

If there is any possibility that an item might be used in vending machines, it would be well to consider this during the design stage. Rigid packages used to be more practical than flexible, but stronger films and heat seals combined with improved structures for both the packages and dispensing machines have expanded the opportunity for pouched products. Very thin items still are difficult to dispense, and oversize packages may limit or completely eliminate this outlet for the product.

The value of the unit package should lend itself to the standard prices in the vending trade. Investigation also will determine whether there is a modular system that requires special dimensions, or whether trade practices or operating characteristics of the machines put special limits on the materials that can be used. A little forethought in the developmental stages may avoid embarrassing compromises or costly changes at a later date.

Material Selection

There is a body of knowledge that can be applied to the solution of packaging problems, but it is somewhat limited in both quantity and quality. Partly because packaging is such a rapidly growing field, as well as a fastchanging one, it is very difficult to get this information documented before it becomes obsolete.

One of the most exciting branches of technology is the field of plastics, and an increasing percentage of all packaging is being made from these versatile materials. However, the glamorous and frequent developments to be seen in plastics should not obscure the usefulness of more mundane packaging materials.

Paper and paperboard are still among the most economical materials and will always be used in a major percentage of containers. Metals have a high degree of strength and rigidity, which are needed for certain applications. Metal in molecular thicknesses or thicker foil webs are still employed to achieve the ultimate in barrier properties for flexible packaging. Glass bottles and jars may be losing share of market in new applications, but often are chosen where an expensive look and stringent barrier properties are a requirement. Even wood has not been replaced in economical structures designed for very heavy goods.

In fact, virtually every material ever invented for packaging is still being used to some degree where it is has a cost/function benefit that is better than any other material. And many materials are now combined to create upgraded functions that cannot be obtained from a single material. Therefore, it is important that students of packaging learn all they can about the old standbys—which are continually being upgraded—as well as exotic new materials (see Table 1.1 for the relative amounts of various materials used in packaging).

Hand in hand with a broad knowledge of materials and packaging forms must go an intimate knowledge of the processes used in the manufacturing and assembling of packages. A thorough knowledge of the methods of making paper and paperboard will help in understanding their properties and in using them to the best advantage. The same can be said of metal, glass, and plastics.

There is also much to be learned about the fabrication and conversion of these materials into finished packages. Various levels of sophistication will be found in different fields, depending on the volume that is being handled and the demands for quality and uniformity. Methods range from completely hand-assembled containers, through semiautomatic operations, to highspeed, fully automatic production lines that turn out containers for the food and beverage industries.

Production Requirements

Still another area of essential technical information is the production line. This includes various techniques used in packaging operations, e.g., cleaning, filling, closing, labeling, wrapping, sealing, and collating.

The diverse nature of these operations and the number of technologies from which they derive make it difficult to plan a curriculum of study. However, as mentioned before, there are an increasing number of books, directories, articles, and trade shows that offer a wealth of information on all of these subjects.

In addition, many vendors are developing improved literature that is sometimes not only technical, but also very educational. Regardless of one's position in packaging, a knowledge of packaging machinery and the functions it performs is a very necessary background.

Specifications

The language of packaging reaches its purest form in the specifications used to document a completed design. This is the means of communicating, in precise terms, with purchasing, manufacturing, quality control, and all the other departments that are directly involved in the execution of the designer's intentions. Properly prepared specifications increase efficiency in all areas, help prevent errors, and should keep costs to a minimum.

This is the concluding phase of the development process, and it becomes a record of the results of the work that has gone on before. When package components are ordered, it is essential that as much information be given to the vendor as possible. A clear understanding at the very beginning may prevent costly errors and delays in delivery. Samples should be approved in writing before full-scale production is started. Tolerances for size, color, density, etc., should be agreeable to both sides, and the basis for acceptance or rejection should be spelled out. Limits should be placed on overruns or under-runs, and penalties for late delivery, extra inspection, or rework ought to be established before the order is placed.

Costs

Any study of packaging inevitably involves a consideration of costs. It is essential to have a good understanding of the various elements that enter into the cost of a package—not only material and labor costs, but also fixed elements that comprise the overall cost of doing business.

A few of the expenses that can be overlooked are control costs for inspection and testing; operational costs involving sterilization, processing, or similar treatment of the finished package; maintenance and supervision; warehousing of raw materials as well as finished goods; and anticipated spoilage.

Whether promotional materials such as retail display containers should be charged to the cost of goods or to a special advertising account will depend on different companies' practices.

The costs of getting a product launched, or even into a test market, are sometimes mistakenly used in calculating profits. To decide whether it would be profitable to go to market with a new product, it is necessary to project the costs ahead several years so that capital investments in tools and equipment can be spread over a reasonable period of time. The advantage of large-volume purchases of materials, where these are possible, should also be taken into account.

TABLE 1.6. How to Estimate Total Product/Package Cost.

Plant Industrial Engineering

Determines the labor needed to manufacture and package the product

Manufacturing

(1) The plant industrial engineer determines the processing equipment needed to manufacture the product.

(2) A time study is performed to determine the crew required to manufacture a product based on the following:

(A) Validated batch preparation, processing and clean-up times

(B) Product configuration time (for extruding, tableting, dicing, etc.)

(3) The total number of direct labor hours (DLH) required to manufacture a product unit (one loaf of bread, 1,000 tablets, 1 lb. or container fill of diced beets) is calculated.

Packaging

(1) The plant industrial engineer determines the equipment needed to package the product.

(2) R & D Packaging Development selects the primary packaging components (product contact elements such as bottles, closures, etc.)

(3) Marketing specifies secondary packaging components (folding cartons, shippers, leaflets).

(4) Regulatory Affairs oversees legal requirements (label copy, hazardous packaging requirements, state environmental restrictions, etc.)

(5) Purchasing obtains budget costs on raw materials and packaging components.

TABLE 1.6 (continued)

(6) A time study is performed to determine the packaging-line crewing, based on the following:

A: Amount of automation warranted

B: Speed at which the line can be operated

C: Condition of the line equipment

(7) The total number of direct labor hours required to package a single unit is estimated:

$$\text{DLH} = \frac{\frac{1}{\text{line speed}} \times \text{number in crew}}{60 \text{ min}} \times \text{efficiency factor}$$

Manufacturing Finance

Receives cost estimate request from the plant industrial engineer. Included are direct labor hours, raw materials, packaging components, volumes, capital expenditure requirements, and any assumptions related to the product.

A double check is made on the information provided by the plant industrial engineer. Is the product new or only a version change? Are there any other like products or like formats?

Estimates are made on the raw materials and packaging components by using data from similar raw materials and components used in similar products or by requesting Purchasing to obtain budget figures from vendors. Product volume will tend to affect the cost of raw materials and components.

Calculate labor costs. Engineer's direct labor hours will be multiplied by a predetermined rate. Rates are broken down into direct labor, variable overhead, and fixed overhead. Hours are the driving force for an activity-based costing system.

Source: Schering-Plough Corp., Madison, New Jersey.

On this basis a standard cost can be estimated, which will be useful until an actual operating cost can be established. A standard cost provides a means of measuring the efficiency of the manufacturing operation in terms of plus or minus variances from the standard, which calls attention to such things as high scrap losses or excess downtime on machines. An example of one approach for the calculation of total product and package cost is described in Table 1.6.

Testing

Another important lesson to be learned in packaging development is the importance of an adequate testing program. Failure to do a careful job of testing can be very costly when the effects are multiplied by the large number of inadequate packages that might be produced, the extra cost of correcting errors, increased waste rates, and loss of customer satisfaction due to damaged goods.

Handbook Structure

This book is designed, first, to acquaint the technologist with the basic facts about the materials and containers of packaging.

In its broadest sense, a package can be considered to be any structure that contains or limits its contents. However, there is a usage of the term outside our scope that causes some confusion. This is the use of "package" to describe an assemblage of wires, controls, and other electronic gear onto a chassis, within a cabinet or enclosed in a coating of melted plastic.

In the packaging field, the subject includes only the more familiar boxes, bags, bottles, cans, crates, cups, and trays of consumer and industrial packaging. Some are very small, such as the metal and plastic aerosols and lipstick canisters that can fit into a purse. At the opposite end of the spectrum, large woven sacks, pallet boxes, crates, bag-in-boxes, and drums hold sizable quantities of liquid and dry products. The materials and processes used to make all of these disparate containers are detailed in Chapters 2 through 16.

This book also is designed to acquaint packaging technologists with the fundamentals of production-packaging operations, line layout, and what machines are required to perform basic packaging functions, as set forth in Chapter 17.

The test methods by which packaging performance is predicted and the quality-control techniques that ensure packages live up to their specifications and performance are outlined in Chapters 18 and 19.

Chapters 20 and 21 are an introduction to the increasing web of laws and regulations that control virtually all packaged products and, most particularly, to the new determination by citizens that packaging shall not end up in their landfills, but be reclaimed for use in new packaging and other products.

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Chapter 2— Paper and Paperboard

History

The earliest records indicate that paper as we know it today was first made at Lei-Yang, China, in the year A.D. 105. The process was invented by Ts'ai Lun, an official in the court of Ho Ti, Emperor of Cathay.

In 751 Muslims captured a Chinese paper mill in Samarkand and forced the workers to reveal the secret process. The Muslims brought papermaking to Spain around 950, and with the beginning of book publishing in the 1450s and the regular publishing of newspapers in 1609, it became an important industry in Europe.

The first paper mill in America was built in 1690 by William Rittenhouse on the banks of the Wissahickon Creek in Philadelphia. The methods used up to that period produced one sheet at a time

It remained for a Frenchman, Nicholas-Louis Robert, to develop a continuous process. His first machine was built in 1799 and was patented in England by the Fourdrinier brothers. Later a cylinder-type machine was invented by John Dickenson and installed near Philadelphia in 1817.

Today, the United States leads the world in the production and use of paper and paperboard, with a per-capita consumption of more than 700 lb (317.5 kg) per year. There are roughly 5,000 plants engaged in manufacturing and converting paper and board.

More than 66 percent of the raw material for paper and paperboard in the United States is wood pulp derived from logs, wood chips, etc., and about 33 percent is recovered wastepaper collected from a variety of sources. Straw, hemp, cotton, flax, and other materials are used to some extent domestically and more so in other parts of the world. According to the American Paper Institute [now the American Forest and Paper Association (AFPA), Washington, D.C.], about 66 million short tons (60.1 million metric tons) of wood pulp were produced in 1995 for paper and paperboard [1]. This tonnage is about equally divided between paper, 0.012 in. (308 m) thick or less and paperboard, greater than 0.012 in. (308 m). Heavy papers in the range of 0.006 to 0.012 in. (154 to 308 m) are sometimes classified as card stock, but for our purposes we will include them with papers. More than 56 percent of the pulp used is derived from pre- and post-consumer secondary materials.

About 5 million short tons (4.6 million metric tons) of paper and 46 million short tons (41.9 million metric tons) of paperboard were used in packaging in 1995. Of the paperboard, almost 70 percent goes into corrugated, and nearly 20 percent into folding cartons and setup boxes. The remainder of the paperboard finds its way into other products such as tubes, cans, drums, and milk cartons and foodservice uses. The value of paper and paperboard products used in packaging in the United States was $31.2 billion in 1995 [2].

The Structure of Wood

Wood is composed of fibres that are about 50 percent cellulose, 30 percent lignin, an adhesive material principally in the middle lamella, and 20 percent carbohydrates such as xylan and mannan, along with resins, tannins, and gums.

In the conversion of wood into paper, the fibres are separated and regrouped to form a felted sheet of the desired dimensions and properties. The methods used will depend upon the type of wood and the purpose of the finished sheet. Because wood is a natural material, there is considerable variation in its makeup. Different species of trees and different growing conditions will result in widely variable fibre structures. “Softwood” is the term used in the paper industry for coniferous or needle-bearing trees, and “hardwood” is applied to deciduous trees, which drop their leaves in the fall.

The chief difference from the papermaker's standpoint is fibre length. Hardwood fibres are less than 0.04 in. (1.0 mm) long, whereas softwood fibres will run up to 0.250 in. (6.4 mm) in length (see Figure 2.1). Hardwoods therefore will make a finer, smoother sheet, but it will not be as strong as one made from softwood. The climate in which a tree is grown also will affect its pulping qualities; northern softwoods have shorter fibres and are more like hardwoods than southern softwoods.

About half of the pulpwood used in the United States for papermaking comes from the southeastern and south central states. Another one-fourth comes from the west south central (Texas, Oklahoma, Arkansas, and

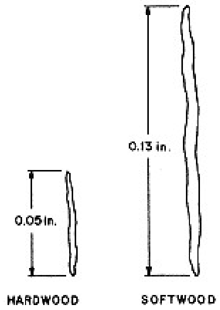

Figure 2.1.
Hard- and softwood fibres vary considerably in size.

Louisiana) and mountain and Pacific states [3]. Most of this is softwood, but hardwoods from deciduous trees also are harvested. Sometimes different pulps are blended to provide papers with special characteristics.

Wood fibres have various forms, depending on their source and on their function in the tree. The fibres which are formed early in the growing season (springwood) have much thinner walls than those produced later in the year (summerwood). Thus, springwood fibres are more flexible and compressible than the summerwood.

The major types of fibres are "vessels" and "tracheids." Hardwoods are a mixture of these fibres, whereas softwoods consist mostly of tracheids. A fibre in cross section looks somewhat like a hollow tube of irregular shape (see Figure 2.2). The open center portion is called the lumen, and this is surrounded by a wall made up of layers, or lamellae, of fibrils. These fibrils, which have diameters of about 1 10^{-6} in. (0.03 m), are made up of microfibrils about one-tenth of this diameter and about 5 10^{-5} in. (1.3 m)

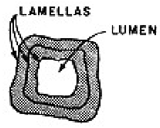

Figure 2.2.
Cross section of a wood fibre, greatly enlarged, shows the lumen (the empty space in the center). The lamellae are layers of fibrils.

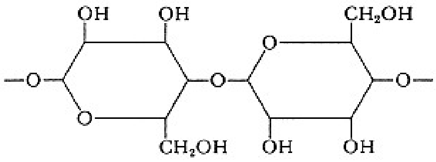

Figure 2.3.
The cellulose molecule is a chain of 100 to 3,000 units in length.

long. These in turn are composed of chains of cellulose molecules (about 3 million in each microfibril) along with short-chain hemicellulose molecules and other polymeric residues (Figure 2.3).

Making Pulp

The lamellae or layers of fibrils are enclosed by spiral windings called the cambium layer. In the pulping process, the fibrils swell and break this outer skin, so that the individual fibrils can extend out and interlock with the hairy surface of other fibres. In papermaking, the water used in the process does not usually go into the crystalline regions of the cellulose molecules, but acts only on the surface of the lamellae.

Although some short-chain polymers will be dissolved, the principal effect of the water is to get between the lamellae and cause the fibres to swell. Individual fibres will increase as much as 20 percent in diameter when thoroughly wet, but only about 3 percent in length. The molecular relationship between water and the fibres is such that water molecules adjacent to the cellulose are held much more tightly than those that are in a water-to-water relationship. This helps to explain some permeability and drying phenomena of cellulose products (see Figure 2.4).

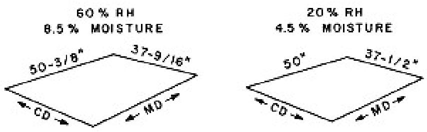

Figure 2.4.
Paper dimensions change depending on moisture content. A kraft sheet of the size shown on the left in a damp atmosphere will shrink only slightly in the crossmachine direction, but almost 1 percent in the machine direction when the atmosphere reaches 20 percent RH.

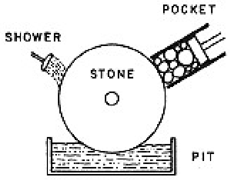

Figure 2.5.
Groundwood pulp is made by pushing logs sideways against a grindstone. Water is sprayed on the stone to carry away the fibres and to help keep the stone cool.

Processing Pulp

After logs are brought to a pulp mill and the bark is removed, one of three methods is used to make pulp: mechanical, chemical, or a combination of the two.

The original mechanical process produces groundwood pulp by pressing the logs against a grinder stone while spraying water over the surface of the stone to carry off the ground material. The stone is cylindrical, and the logs are held against the side, parallel to the axis of the stone, so that the full length of the log is ground at the same time (Figure 2.5). This method is mostly used for northern softwoods. All components of the wood are utilized in this process; that is, the lignin and carbohydrates, which make up half the wood, are not removed. Groundwood pulping has largely been replaced by a thermomechanical method, where the wood is ground in a refiner and then heated under pressure to soften the particles.

About 10 percent of the pulp used in paper and paperboard is the mechanical type. It is the least expensive kind of virgin pulp, but generally is not used alone, due to low strength. For packaging papers, it is mixed with chemical pulp.

The chemical pulping process, in contrast to mechanical pulping, cooks the wood with chemicals to remove the lignin and carbohydrates and yields a higher and more expensive grade of pulp (see Table 2.1).

There are three processes. The oldest, the soda process, was discovered in England in 1851 but is rarely used anymore in the United States. In this method caustic soda (sodium hydroxide) and soda ash (sodium carbonate) are used to dissolve the undesirable components of the wood. The soda process is generally used with hardwood pulps.

The sulfate process, also known as the kraft process, is used on both hardand softwoods. Sodium sulfide replaces the sodium carbonate used in the previous method; otherwise the processes are similar. The strongest pulp

TABLE 2.1. Types of Pulp Used in Paper and Paperboard.

Type of Pulp	Percentage Used
Mechanical	10
Chemical	
Soda	1
Sulfate	79
Bleached	45
Unbleached	32
Sulfite	2
Semichemical	6
Dissolving	1

products are made by this method, hence the name *kraft,* the German word for strength.

Sulfate pulp is brown and requires bleaching to produce white paper and paperboard, whereas soda pulp is lighter in color, finer in texture, and somewhere between the groundwood and kraft pulps in strength. Nonetheless, the largest percentage of paper pulp is made by the sulfate process. It finds its way into a variety of products (Table 2.2).

The sulfite process is an acid reaction, in contrast to the soda and the sulfate processes, which are strongly alkaline. The cooking liquor is a solution of calcium or magnesium bisulfite and sulfurous acid. It is used on both hardand softwoods and yields a light-colored pulp that is stronger than soda pulp but not as strong as kraft. About 1 percent of the pulp produced is of this type. Sulfite pulps generally are used for fine papers, but not for archival stock, as the residue of acid in these papers causes deterioration over time.

Semichemical pulp is produced by a combination of chemical and mechanical means. First, there is a soaking in caustic soda or neutral sodium sulfite to soften the lignin and carbohydrates, which bind the fibres together. This is followed by grinding in a disk refiner. This method is used mainly with hardwoods and results in a low-cost pulp with most of the lignin retained.

TABLE 2.2. Markets for Kraft Paper.

Market	Share (Percent)
Grocery Bags and Sacks	40
Multiwall Shipping Sacks	38
Wrapping & Converting Papers	17
Other Bag & Sack	5

Semichemical pulp is difficult to bleach and turns yellow when exposed to sunlight. For applications in which strength and stiffness are needed and color is not important, as in corrugating medium, it is often used. About 6 percent of all pulp produced for paper and paperboard is the semichemical type.

Digesters, which are used to cook pulp, operate at around 300+ F (149+ C) under pressures of about 100 psi (0.690 kPa). Wood that has been converted into small chips is cooked for several hours and then blown down into a "blow tank." From there it is pumped into knotters where knots are removed and then to a washer line where liquor is reworked for reuse. Screening before or after washing reworks coarse fibres.

Washing is followed by bleaching with one or more chemicals, such as calcium hypochlorite, hydrogen peroxide, or chlorine dioxide. Since bleaching reduces the strength of the pulp, it is necessary to reach a compromise between the brightness of the finished sheet and its tensile properties. Loss of strength can be minimized to some extent by the choice of chemicals and by bleaching in several stages. The bleaching process has been criticized for producing highly toxic dioxin residues in paper and board and mill waste water. However, today it is possible to produce bleached paper and boards with no detectable levels of dioxin.

Papermaking

The slurry for making paper is composed of 97 percent water and 3 percent solids. This is put into a beater, where metal bars or knives rub against the fibres. As bundles of fibre are broken up, hydration takes place; that is, the fibrils combine chemically and physically with water to become thoroughly "wetted" so they swell. As the fibres swell, the cambium layer breaks, and the fibrils open out in a process known as fibrillation. Some shortening or breaking of the fibres is inevitable, but every effort is made to retain as much fibre length as possible.

A small amount of beating will produce a highly absorbent sheet with high tear strength but low burst and tensile strength (see Figure 2.6). With more beating, the paper will have higher burst and tensile strength, but a decrease in tear resistance up to a point where the burst strength also starts to fall off. A good example is glassine paper, which is carried to almost complete fibrillation.

Sizing materials such as rosin, starch, and papermaker's alum are added in the beater to provide water resistance and ink holdout. Without sizing, it would be difficult to print on the paper because the ink would spread and soak into the sheet. The amount of sizing also will affect the behavior of adhesives that may be used later in making packages.

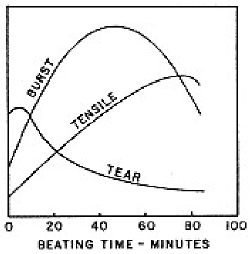

Figure 2.6.
Beating curves show how a small amount of beating makes a very absorbent paper with high tear strength. With more beating, the paper becomes more dense, but the tear strength falls off.

Other materials can be added in the beater as filler or to impart properties such as color, opacity, and stiffness. These additives might include titanium dioxide, sodium silicate, diatomaceous earth, casein, wax, and talc. When the stock leaves the beater, it is passed through a high-speed conical or disk refiner, which continues the beating process. At this point, different pulps may be added to impart desired properties in the finished sheet.

From there, this mixture of pulp, sizing, and fillers, known as the "furnish," goes into the "headbox," ready to start through the papermaking machine.

Papermaking Machines

In brief, the papermaking process follows these steps. The prepared wood fibres are suspended in a large amount of water (99.5 percent water, 0.5 percent cellulose) and fed onto a moving screen belt or "wire" from a headbox in one process or, in another, is picked up by a screen cylinder as it passes through a pool of fibre slurry.

As the water is removed by gravity and suction, fibres are deposited on the moving screen. Since thin areas of fibre will have a higher rate of flow, other fibres will move in their direction, thus tending to produce a more uniform sheet. Because coarse fibres, being heavier, settle more quickly than finer ones, the side of the sheet toward the "wire" always has a rougher surface than the top "felt" side (see Figure 2.7).

This buildup of fibres on the screen results in a layered structure in which most fibres would tend to lie in parallel and tilt slightly toward the wire due to the high rate of water drainage as the belt travels over the table rollers. The orientation of fibres in a single direction gives the paper or board what is known as "grain." A paper made this way would consist of layers that could readily delaminate and/or tear in the machine direction.

The ideal structure is a felted material in which fibres interweave with other fibres at different levels and in both the machine and cross-machine directions of the screen. Recent advances in paper-machine design now include the use of several headboxes that can feed different kinds of pulp. Improvements in on-machine sensors and computer control of these feedstocks have greatly improved the cross-linkage of fibres.

The technical advances are very timely because of the increased use in both papers and boards of high concentrations of recycled fibre; a trend both desired and often mandated in this era of environmental concern and the public desire to recycle rather than throw away (see Chapter 21, Packaging and the Environment).

When the fibre slurry is first laid on the machine screen, fibres are in suspension, but as the water drains off and the paper reaches a 40:60 ratio of fibre and water, the remaining water is within and not between the fibres. At this point, no more water can be squeezed out but must be evaporated by heat. This is the function of the entire dryer section of a papermaking machine.

The fibres shrink as they dry and if the sheet is very dense, the shrinkage can be considerable. An open, poorly bonded sheet, on the other hand, allows the fibres to slide where they cross each other, and the shrinkage of the finished sheet is greatly minimized. In either case, strains are set up within the fibres at the points where they cross; and anything that affects this strain relationship, such as a change in moisture content, can cause the sheet to expand, contract, curl, or cockle.

Machines for papermaking are often as long as a city block and several stories high. Some of the newer machines produce paper up to 30 ft in width at 3,000 ft per minute, equivalent to 1,000 tons per day. Paperboard up to 30 ft in width runs at about 80 percent of that speed.

Two basic machines are in use today: the fourdrinier and the cylinder (see Figures 2.8 and 2.9). Thin paper and kraft board is typically made on a four-

Figure 2.7.
Paper and paperboard surface texture is always rougher on the "wire" side than the "felt" side because coarse fibres settle more quickly than finer ones.

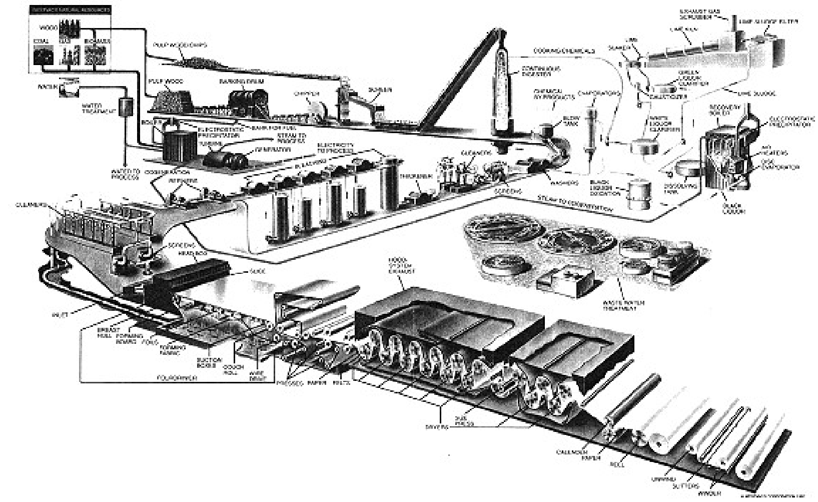

Figure 2.8.
In the fourdrinier papermaking process, logs are chipped and cooked in the pulp mill to separate the fibres in what is essentially a chemical operation. The fibres are then sent to the paper mill and refined by mechanical processes to open up the fibres. Next, a dilute suspension of pulp is spread on a moving screen belt in the fourdrinier so water passes through, leaving a mat of wet paper, which is pressed, dried, and finished. (Reprinted with permission. 1982 Westvaco Corporation, New York.)

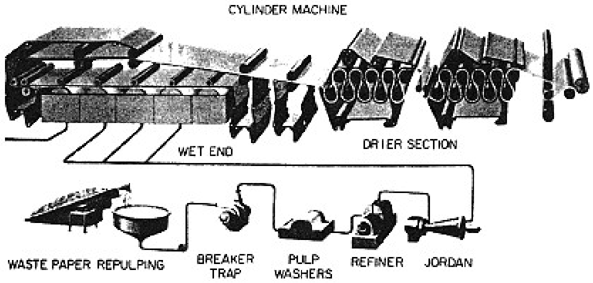

Figure 2.9.
The cylinder machine generally makes heavy grades of recycled paperboard from waste material with a layer of high-grade pulp on the outside. Screen-covered cylinders pick up a layer of pulp from a vat and deposit it on the underside of a felt blanket. Several layers are built up on the felt and then carried into the drier section. Finished paperboard may be rolled or sheeted.

drinier machine, while multi-ply paperboard is made on a cylinder machine. A third type, the Inverform machine, combines the endless wire of the fourdrinier with the multiple headboxes of the cylinder machine (although multiple headboxes are now used on some fourdrinier machines, as well).

The cylinder machine has a series of six to eight wire-mesh cylinders rotating in individual vats. These "wires" carry the pulp upward and deposit it on the underside of a moving felt blanket, which is pressed against the cylinder by a rubber "couch roll." Each screen adds another layer. Frequently, the first and last vats will have a higher grade of pulp, while the vats in between will contain wastepaper and other reclaimed material blended with a certain amount of virgin pulp.

The printing surface, which is composed of the highest quality pulp, is called the "top liner." The opposite side is known as the "back liner." The plies in between are called the "filler." Occasionally, an under liner of highgrade pulp is used just below the top liner when the ultimate in quality is sought. With the fourdrinier machine, this great combination of different materials is not yet possible, but the increased use of extra headboxes has enhanced its versatility.

The other important difference between these two processes, from a packaging standpoint, is that there is more grain in a cylinder sheet than in a fourdrinier sheet. Therefore, the fourdrinier sheet is smoother and softer, and cylinder board is stiffer. In fact, the stiffness ratio (machine direction versus cross direction) of cylinder kraft linerboard is about 4:1 compared to about 2:1 for fourdrinier kraft linerboard. As shown in Figure 2.10, stiffness also is influenced by fibre weight.

The reason for this difference is that in a fourdrinier machine the slurry flows out of the headbox through a narrow slot controlled by a long, sharpedged plate known as a "slice." The slurry falls on a moving synthetic or steel/synthetic screen belt as it comes up around a "breast roll" and is carried

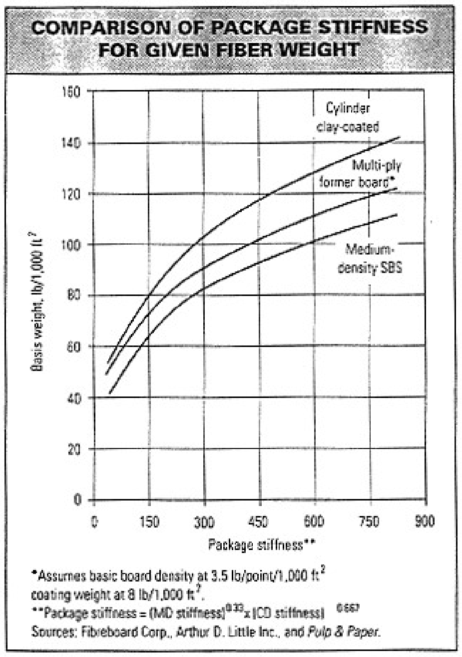

Figure 2.10.
Cylinder sheets have more grain than fourdrinier sheets and, thus, are stiffer. Stiffness also increases as basis weight increases. Different sheets require different amounts of fibre to achieve the same stiffness. (Source: Pulp & Paper 1996 North American Factbook. Copyright 1996.Reprinted by permission of Miller Freeman, Inc., San Francisco.)

along over a series of table rolls where some of the water runs out, then over some suction boxes where more water is removed.

As it moves, the screen is shaken from side to side about 200 times per second, causing the fibres to be laid in a more random crisscross fashion, which improves the strength of the resultant board.

A small roll above the wire near the end, called the dandy roll, is used to apply a watermark or improve formation. The pulp leaves the screen at this point and moves unsupported for a very short distance to the press rolls. A woolen felt blanket then carries it between rolls where more water is squeezed out.

From the press rolls, the web is carried into the dryer, where it passes through steam-heated rolls—as many as 150 in several multiple stacks, operating at temperatures of 150 to 275 F (66 to 135 C)—until only 4 to 8 percent of the moisture remains. On some tissue paper machines and for lightweight, thin papers up to about 35 lb per ream (57 g per m^2), a single large roll about 12 ft (3.7 m) in diameter, called a “yankee dryer,” is used in place of the banks of smaller rolls.

Various coatings and additives can be applied on the paper machine or later in off-line operations. Typical are pigments such as kaolin clay, titanium dioxide, and calcium carbonate; adhesives like proteins, starches, or lattices; and additives such as waterproofing agents, oil/grease repellents, fire retardants, dyes, and preservatives. One common surface treatment applied while the paper is still on the machine to improve the printing characteristics and stiffen the sheet, dips the paper into a clay/starch solution and then squeezes it between rolls.

The paper also can be “calendered” before it leaves the machine by being ironed through a series of powerful stacked rolls. Calendering produces a surface gloss by smoothing out and polishing surface coatings. It also increases the density and smoothness of the surface, but reduces brightness, opacity, and caliper. Thus, although density increases, stiffness decreases. This loss of stiffness is proportional to the cube of the caliper reduction. When great strength and stiffness are important, excessive calendering and supercalendering should be avoided.

Matte finishes are produced by light calendering or none at all. To produce a matte finish, the thickness of a coating is reduced and the paper is very lightly calendered. Matte materials measure from 7 to 20 on the gloss scale, dull coateds measure from 20 to 50 and gloss coateds measure upward from 50.

Variations in processing along with differences in the starting materials provide an infinite number of differences in finished sheets. Not only does the same type of paper vary according to manufacturer, but even mills within the same company often cannot duplicate one another's products. For consistent packaging results, therefore, it is well to know the source of the papers and boards, which are used, and to specify this source rather than to depend on specifications that are based solely upon physical tests.

Types of Paper

Two broad categories of paper are being used today: industrial and fine. Nearly all of the papers used for packaging fall into the industrial papers classification. Fine papers are used for writing, bond, ledger, book, and cover papers.

An important piece of knowledge for all packagers is how papers and boards are measured. Fine papers are specified by the weight of a standard ream composed of 500 sheets, usually measuring 24 × 36 in. (61 × 91 cm), which totals 3,000 ft^2 (279 m^2) of paper. Paperboard is measured differently (see page 49).

The strongest and most useful paper for packaging is that known as natural kraft (NK). Light brown in color unless bleached, it is made by the sulfate process in basis weights from 18 to 200 lb (8.2 to 90.7 kg) per ream with the most common weights falling in the 25- to 80-lb (11.3- to 36.3-kg) range.

Kraft paper sometimes is not calendered so that when it is made into bags, the rough surface will prevent them from sliding off the pile. More often, kraft is given a smooth finish in the calender stack on the paper machine. An MG (machine-glazed) finish can be made on a very large highly polished drying roll. NK is used almost universally in industrial bags and corrugated linerboard (see Chapter 5, Bags, Sacks, and Pouches and Chapter 14, Corrugated Fibreboard, respectively).

Creped kraft paper is made by slowing down the press rolls in relation to the wire speed so that the paper builds up and crepes on the press roller. The angle of the doctor blade, which scrapes the paper off the roll, also helps crepe the paper. Up to 300 percent stretch in one direction can be put in by this method.

Extensible paper is made by carrying a web of wet paper between a rubber blanket and dryer drum. As the drum, paper, and blanket rotate, the blanket is stretched by compression between a nip roll and the drum. As rotation continues, the blanket returns to its original dimension pulling and compressing the paper web with it (Figure 2.11). This mechanical shrinkage can increase the ultimate stretchability of this paper up to 500 percent. Tensile strength is lessened by about 25 percent. The process has little effect on cross-machine strength or stretch. For applications requiring great impact strength such as multiwall bags, this built-in stretch not only imparts much greater strength, but also can permit reduction in the total basis weight or

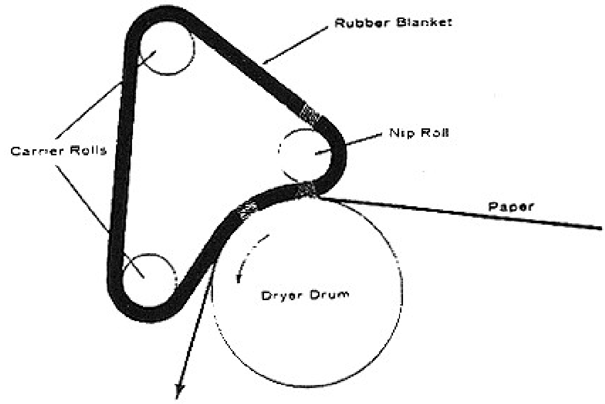

Figure 2.11.
Extensible paper is produced mechanically by compressing a paper web between a rubber blanket and drying roller. As the blanket stretches and then returns to its original size, the paper web does the same, producing considerable latent stretch in the machine direction. (Source: Stone Container Corp., Chicago.)

the number of plies. Extensible paper can be coated, laminated, calendared, and treated in the same way as conventional NK [4].

Bleached and semibleached krafts are the strongest white papers, although they lose some of their inherent strength in the bleaching process. They are used when good printing is a requirement and where the nature of the products, such as foods or pharmaceuticals, require a package that has a clean appearance. Bleached papers tend to be more expensive than unbleached (see Table 2.3).

Wet-strength papers are made by adding polyamide or polyamine resin to

TABLE 2.3. Basis Weights and Prices for Various Packaging Papers

Paper Type	Cost per Ton
Lightweight Bleached Pkg Papers	$960
30-lb Bleached Grocery Bag	$900
30-lb Unbleached Grocery Bag	$720
50-lb Unbleached Kraft Shipping Sack	$690
70-lb Unbleached Grocery Sack	$500

Source: Pulp & Paper Week, Miller Freeman, Inc., San Francisco.

the paper stock. After curing with heat, which takes but a few minutes, or at room temperature over a couple of weeks, paper treated in this manner will retain 25 to 30 percent of its dry tensile strength when saturated with water. These papers are often the outer liners in boxes or multiwall sacks exposed to adverse environmental conditions. For easy identification, wet-strength paper usually is printed across the width with longitudinal stripes, measuring at least 1/8 in. (3.2 mm) wide on 2- to 10-in. (5.1- to 25.5-cm) centers.

Glassine and greaseproof papers are made by prolonged beating in the pulping process. The appearance and properties of these papers are due entirely to the working of the pulp, not to any additives. The term "greaseproof," as applied to paper, refers to a class of material rather than to its properties. It does have a high resistance to grease, fats, and oils, as its name implies. It is not, in and of itself, moisture-proof. However, it does provide an excellent surface for moisture-proof coatings, such as wax and lacquer, which may be applied as a top coating. It also has been incorporated in laminations, sandwiched between two other sheets.

Glassine is basically greaseproof paper that has undergone a second operation: redampening and super calendering under high pressure and heat. This produces a glass-like surface, hence the name. Both glassine and greaseproof papers can be treated in other ways to change or enhance their properties by the addition of plasticizer additives for softness and pliability, release coatings for sticky products, antioxidants to retard product rancidity, and inhibitors to prevent molds, yeasts, and fungi from developing.

Glassine and greaseproof papers have been used in bags, pouches, and wraps and as linings in boxes and cartons for foods, tobacco products, chemicals, and metal parts. However, in recent years, many of these applications have gone to plastic-coated papers or to film pouches and bags.

Parchment papers usually refer to vegetable parchment, although greaseproof paper is sometimes called mechanical or greaseproof parchment. True parchment paper is made by passing a web of "waterleaf" (a high-quality unsized chemical pulp) through a bath of sulfuric acid, after which it is thoroughly washed and dried on conventional papermaking driers.

The acid attacks the surface of cellulose fibres, forming a jelly-like amyloid similar to laundry starch. It fills the interstices between the fibres, yielding a material with high tear strength, which has the unique property of being stronger when wet than when dry. It is available in basis weights ranging from 15 to 120 lb (6.8 to 54.4 kg) per ream, but the most commonly used basis weights are 27, 35, and 45 lb (12.2, 15.9, and 20.4 kg).

Parchment has good grease resistance, especially in the heavier weights, and excellent wet strength even in boiling water. It also has a fibre-free surface and is odorless and tasteless. Vegetable parchment is not a good barrier for gases, except possibly in the heavier weights, unless it is coated with a material for that purpose (see Chapter 4, Coatings and Laminations). But, it is used as wraps for certain moist, greasy, frozen, or dry foods and as carton liners for foods and industrial products.

Waxed papers can be made from almost any type of paper. The question of which basic sheet to use generally comes down to a matter of whether it needs to be a high grade of sulfite paper for food packaging or a lower grade for a less demanding application. There are several ways of incorporating the wax into the paper. It can be added in small amounts as a sizing in the papermaking process or applied to the finished sheet as a dry- or wet-wax treatment.

The basic material is paraffin wax, which has a melting point between 115 to 165 F (46 to 74 C), blended with one of the following: microcrystalline wax, ranging from 130 to 190 F (54 to 88 C); polyethylene in the range of 195 to 255 F 91 to 124 C); or petrolatum, which melts between 105 to 125 F (41 to 52 C).

When paper is coated with wax and is carried over heated rollers so that the wax is kept fluid and soaks into the paper, it is called “dry-wax” paper. If the hot rolls are omitted, the wax solidifies on the surface to produce what is called “wet-wax” paper. The wax can be applied to one or both sides of the paper. Generally, dry-wax paper offers less protection from moisture than wet-wax paper. “Wax-sized” papers, in which the wax is added at the beater during the papermaking process, have the least amount of wax and, therefore, provide the least amount of moisture protection.

Waxed paper is one of the lowest-cost moisture barriers and offers good grease resistance and heat-sealing characteristics, as well, making it very useful for packaging such things as food, soap, tobacco, and similar products that require moisture protection.

At the other end of the scale, are papers designed to dissolve in water. Water-soluble coatings of ethylene vinyl acetate or polyvinyl alcohol impart heat-sealability for conversion into bags or pouches while pressure-sensitive labelstocks for refillable containers or other uses can be made using a water-soluble adhesive. Dissolvable pouch packaging allows ingredients that are mixed with water to be premeasured and minimizes contact with corrosive or toxic products. Available in thicknesses from 0.003 to 0.008 in. (77 to 205 m). the stock has the appearance and texture of bond paper and can be printed and fabricated in much the same way. The papers are not affected by high humidity. Solubility rates can be slow or fast and are influenced by water temperature and pH.

Nonwovens and “Synthetic” Paper

Not all paper is made from wood fibres. These so-called “synthetic” papers act much like paper but provide added durability and ultraviolet stabil-

TABLE 2.4. Properties of Synthethic Papers

Material	Cost per lb, $	Cost per 1000 in.^{2}/mil	Gauge (mils)	Gauge (m)	Basis weight lb/500 sheets
Spun-bonded HDPE (Tyvek)	5.20–6.60	0.38–0.84	5.7–7.6	146–195	1.6–2.2
Filled, biaxially					
cast PP (Kimdura)	3.50	0.30–1.10	3.0–12.0	77–308	30–155
Nonwoven polyester (Reemay)	6.88	0.33	7.0	179	20
Teslin	3.40–4.14	0.52–2.07	7.0–18.0	179–461	73–238

25 38 inch sheets.

Material	Tensile Strength MD (lb/in.)	Tensile Strength CD (lb/in.)	Brightness	Opacity (percent)	Burst Strength lb/in.^{2}
Spun-bonded HDPE	32–46	35–50	NA	91–97	110–270
Filled, biaxially					
cast PP	18–70	50–200	96	90–100	
Nonwoven polyester	15	14	NA	NA	20
Teslin	10.5–22.1	5.3–13.5	89–92	92–100	NA

Too high for std. equipment measurement.

ity. Made by a variety of methods, each has distinctive qualities, making it suitable for specific end uses (see Table 2.4).

One example is a spun-bonded polyolefin. In appearance, this high-density polyethylene (HDPE) fibre material resembles a slick paper with good whiteness and exceptional strength. It has no grain and does not shrink and expand with changes in humidity. It is lint-free and resistant to staining and to mold and mildew growth. Chemical resistance also is excellent.

A major feature is that the material is porous and permits the free passage of sterilizing gases while blocking the passage of microorganisms. Obviously, a major usage is in medical packaging. The material used for packaging is stiff (a more flexible form is used in hospital garments). Most inks suitable for paper or film printing can be used without special treatments. On the down side, it costs more than paper, with tray-cover and label stock selling in a range of about 38 to 84 cents per 1,000 in.^{2} (6451.6 cm^2).

Another synthetic made from HDPE fibres has been developed for inmold labeling applications. Targeted for use on HDPE bottles, the labelstock provides recycling compatibility.

Labeling also is the main packaging use of a tear-resistant, biaxially oriented, two-side-clay-coated HDPE. Typically used in pressure-sensitive structures, it offers high-quality print reproduction, dimensional stability, and resistance to water, grease, and some chemicals.

A laminate of calcium carbonate-filled biaxially cast polypropylene also offers superior print quality making it well- suited for labels and book jackets.

A nonwoven polyester alternative to filter paper is being used in boil-in-bag and gourmet tea and coffee packet applications. The synthetic material is two to three times stronger and about 30 percent more expensive. However, unit costs can be comparable because oils are not absorbed so less flavoring is needed.

Types of Paperboard

Paperboard is measured in pounds per ream, which is 1,000 ft^2. Basis weights range from 26 lb (11.8 kg) to about 90 lb (40.8 kg) with thicknesses from 0.009 to 0.030 in. (231 to 769 m). Some cylinder boards can actually go as high as 0.060 in. (1.5 mm). Another common measurement of thickness in packaging materials, the "point," is equal to 0.001 in. (25.6 m).

Thickness usually is specified by "regular number," which is the number of 1,000-in.^{2}, 25 40 in. (6,451.6-cm^2, 63.5 101.6 cm) sheets in a 50-lb (22.7-kg) unit called a "bundle." Thus, the lower the number, the heavier the board. The regular number should not be confused with "count," which is the actual quantity of sheets of any given size in a 50-lb (22.7-kg) bundle.

TABLE 2.5. Brightness of Typical Boxboards.

Type of Boxboard	Reflectance (Percent)
Unbleached Natural Kraft	20–25
Semi-Bleached Kraft	26–60
Single Manila-lined Chip	42–46
Bleached Manila-lined Chip	56–60
White Patent-coated News	66–70
Super White Patent-coated News	71–75
Machine Clay-coated News	74–78
Fully Bleached White Kraft	77–85
Brush Clay-coated (Off Machine)	78–80

Magnesium oxide = 100.

Brightness, a highly desirable characteristic, is given in reflectance values as a ratio of comparison with magnesium oxide, which scores 100. It is dependent on furnish quality and bleaching method, along with any fillers and coatings. The figures in Table 2.5 can be thought of as percentages of a dead white (measured on GE brightness scale).

Also dependent on the furnish, as well as the paper-making machine, is the finish or density of the board and its smoothness. Finish is designated No. 1, 2, 3, or 4 with No. 1 being the lowest density (see Table 2.6).

There are many types of paperboard. Containerboard is the largest single grade with roughly 23 million short tons (20.9 metric tons) consumed in 1995, according to the Fibre Box Association, Rolling Meadows, IL. Corrugated boxes are now used to carry more than 90 percent of the goods produced in the United States. So universal is this distribution packaging material that its sales per year can be used as a rough measure of the national economy.

TABLE 2.6. Boxboard Finishes.

No. 1	Low density and generally rough surface with high area per pound of board
No. 2	Greater density than No. 1 with generally smoother surface and usually satisfactory for ordinary printing
No. 3	Greater density than No. 2 with generally smoother surface and usually intended for high quality printing
No. 4	Very dense board made to obtain extreme smoothness, produces lowest yield

Source: American Forest and Paper Association, Washington, D.C.

Containerboard has two paper components—linerboard and corrugating medium—from which corrugated and solid fibreboard boxes are manufactured.

The corrugating "medium" is made principally in a 26-lb (11.8-kg) basis weight and is 0.009 in. (231 m) thick, and usually is produced from hardwoods by the sulfate process (see Figure 2.12). Today, however, it also can contain a significant proportion of post-manufacture and post-consumer recycled paper and paperboard (see Chapter 21, Packaging and the Environment).

Linerboard sheets, which are glued to one or both sides of the corrugating medium, are made from southern pine and other softwoods, generally on a fourdrinier machine, and are also called kraft. However, some linerboard is made on a cylinder machine with a filler of wastepaper and liners of kraft paper. It is known as "jute." Linerboard is made in a range of weights from 26 to 90 lb per 1,000 ft^2 basis weight (11.8 to 40.8 kg per 93 m^2) in thicknesses ranging from 0.009 to 0.030 in. (231 to 769 m).

Solid fibreboard is a sheet that has been produced or laminated to a thickness that provides great stiffness and strength. It is generally three or four plies consisting of two outer liners and fillers and ranges in thickness from 0.060 to 0.140 in. (1.5 to 3.6 mm). It is used mostly for industrial packaging and other box applications requiring maximum strength and physical endurance.

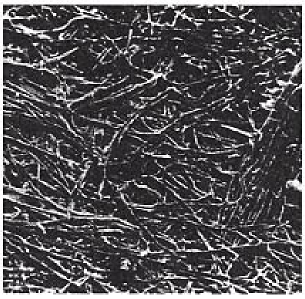

Figure 2.12.
This 60 photomicrograph shows the felt side of a corrugated medium sample composed of 80 percent semichemical, 11 percent refined kraft screenings, 5 percent machine broke post-manufacture reyclings) and 4 percent kraft pulp. (Source: U.S. Forest Products Laboratory, Madison, Wisconsin.)

Chipboard is a low-quality paperboard made from waste and recycled papers and is used where strength and quality is relatively unimportant. In its manufacture, old newspapers and other scrap papers are put through a beater with various sizing materials and fillers. This furnish then goes through the regular papermaking process. It is available in a wide array of gauges and densities and often is used to make tubes, cores, canisters, etc.

When this material is made into lightweight papers, it is known in the trade as "bogus." This type of paper, sometimes indented to give it more cushioning capability, is widely used to protect glassware and other fragile articles in shipment. Although bogus paper also can be used for wrapping, it has very little tensile strength and most often serves merely as a separator or is crumpled and stuffed into void spaces as a filler.

When used in "folding boxboard" for paperboard cartons, enough long

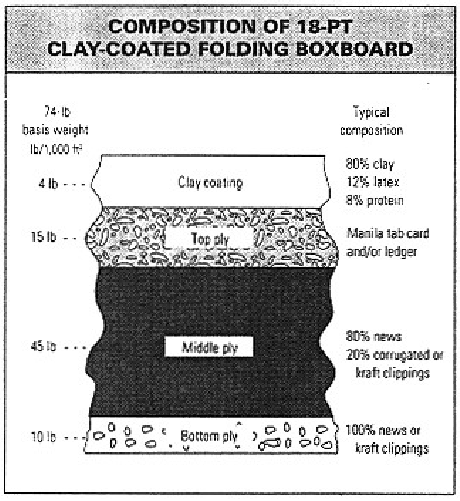

Figure 2.13.
Most lightweight folding cartons for food and nonfood products are made from clay-coated recycled paperboard with a structure similar to the one shown. Grades can be identified by the color of the unprinted side: gray for newsback; brown for kraft; and white for white-lined. (Source: Pulp & Paper 1996 North American Factbook. Copyright 1996. Reprinted by permission of Miller Freeman, Inc., San Francisco.)

TABLE 2.7. Grades of Nonbending Board.

Regular No. 50-lb Bundle Quantity	Finish (Density) 1 in.	2 in.	3 in.	4 in.	Weight per M ft^2 lb	Weight M Sheets 25 40 lb
35	.065	.062	.058	.053	206	1429
40	.057	.054	.051	.046	180	1250
45	.051	.048	.045	.041	160	1111
50	.046	.043	.040	.037	144	1000
55	.041	.038	.036	.033	131	910
60	.038	.035	.033	.030	120	833
65	.035	.032	.030	.028	111	771
70	.032	.030	.028	.026	103	715
75	.030	.028	.026	.024	96	667
80	.028	.026	.024	.022	90	625
85	.026	.024	.023	.021	85	590
90	.024	.022	.021	.019	80	556
95	.023	.021	.020	.018	76	528
100	.021	.020	.019	.017	72	500
110	.019	.018	.017	.016	65	451
120	.017	.016	.015	.014	60	417

Includes plain chipboard, news vat-lined chipboard, filled news board, white vat-lined chip.

Source: American Forest and Paper Association, Washington, D.C.

fibres must be applied in the top and back liners to provide greater strength and necessary folding characteristics. Usually a top liner of recycled kraft pulp is put on one side in the papermaking machine. Sometimes the back liner is made of recycled newspapers, which have gone through a deinking process. This is called "newsback." A white liner can be put on the back as well as the front, if this is desired, by using bleached pulp blended to the brightness needed (Figure 2.13). Folding cartons made from these combination boards are used for a vast number of moderately priced consumer products such as dry foods, toiletries, over-the-counter drugs, toys, games, and household products.

Boxboards are made in bending and nonbending grades (see Tables 2.7 to 2.13). Although there are lighter and heavier gauges, the most common board thicknesses range from 12 to 30 points (307 to 769 m), with the majority falling between 16 to 24 points (410 to 615 m). Boards that are heavier than 32 points (821 m) are used in "nonbending" packaging that does not require folding or creasing (see Tables 2.7, 2.11, 2.12, and 2.13). However, thinner nonbending boards also are available.

TABLE 2.8. Gauges and Densities of Bending Board.

Regular No. 50-lb Bundle Quantity	Finish (Density) 1 in.	2 in.	3 in.	4 in.	Weight per M ft^2 lb	Weight M Sheets 25 40 lb
40	.053	.050	.047	.045	180	1250
45	.047	.045	.042	.040	160	1111
50	.042	.040	.038	.036	144	1000
55	.038	.036	.034	.032	131	910
65	.031	.030	.028	.026	111	771
70	.029	.028	.026	.024	103	715
75	.027	.026	.024	.023	96	667
80	.025	.024	.022	.021	90	625
85	.023	.022	.021	.019	85	590
90	.021	.020	.019	.018	80	556
95	.020	.019	.018	.017	76	528
100	.019	.018	.017	.016	72	500
105	.018	.017	.016	.015	69	479
110	.017	.016	.015	.014	65	451
120	.016	.015	.014	.013	60	417

Includes bending and semi-bending chipboard; cracker-shell board; colored boxboard chip back; mist colored suit boxboard chip back; single manila chip; bleached manila-lined chip; double manila-lined chip; bleached manila extra strength jute, kraft or pulp back.

Source: American Forest and Paper Association, Washington, D.C.

TABLE 2.9. Gauges and Densities of Patent-coated and Machine-Clay-Coated Boards (Bending).

Regular No. 50-lb Bundle	Caliper of Individual Sheets	Weight per M ft^2	Weight per M Sheets 25 40
45	.040	160	1111
47	.038	152	1964
50	.036	144	1000
53	.034	136	943
56	.032	128	893
60	.030	120	833
64	.028	112	781
69	.026	104	725
75	.024	96	667
82	.022	88	610
88	.020	82	568
93	.018	77	538
104	.016	69	481
111	.015	65	450
114	.014	63	439
120	.013	60	417
128	.012	56	391
141	.011	51	355

Source: American Forest and Paper Association, Washington, D.C.

TABLE 2.10. Gauges and Densities of Double-lined and Extra Strength Patent White, Solid Manila and Machine-Clay-Coated Boards (Bending)

Regular No. 50-lb Bundle	Caliper of Individual Sheets	Weight per M ft^2	Weight per M Sheets 25 40
44	.040	164	1136
46	.038	156	1087
49	.036	148	1020
51	.034	140	980
54	.032	132	926
58	.030	124	862
62	.028	116	806
67	.026	108	746
72	.024	100	694
78	.022	92	641
85	.020	85	588
90	.018	80	556
100	.016	72	500
104	.015	69	481
111	.014	65	450
114	.013	63	439
124	.012	58	403
136	.011	53	368

Source: American Forest and Paper Association, Washington, D.C.

TABLE 2.11. Gauges and Densities of Solid News and Solid Groundwood Pulpboard (Nonbending).

	Finish (Density)					
Regular No. 50-lb Bundle Quantity	1 in.	2 in.	3 in.	4 in.	Weight per M ft^2 lb	Weight M Sheets 25 40 lb
40	.061	.058	.054	.049	180	1250
45	.054	.052	.048	.043	160	1111
50	.049	.047	.043	.039	144	1000
55	.045	.043	.039	.035	131	909
60	.041	.039	.036	.032	120	833
65	.038	.036	.033	.030	111	769
70	.035	.033	.031	.028	103	714
75	.032	.031	.029	.026	96	667
80	.030	.029	.027	.024	90	625
85	.028	.027	.025	.023	85	588
90	.026	.025	.023	.021	80	556
95	.025	.024	.022	.020	76	526
100	.023	.022	.021	.019	72	500
110	.021	.020	.019	.017	65	455
120	.019	.018	.017	.015	60	517

Source: American Forest and Paper Association, Washington D.C.

TABLE 2.12 Gauges and Densities of Pasted Chipboard (Nonbending).

Regular No. 50-lb Bundle Quantity	Finish Rough in.	Smooth in.	Weight per M ft^2 lb	Weight per M Sheets 25 40 lb
10	.216	.206	720	5000
15	.144	.138	480	3333
20	.108	.103	360	2500
25	.086	.081	288	2000
30	.070	.065	240	1667
35	.060	.058	206	1429

Source: American Forest and Paper Association, Washington, D.C.

Heavier-weight boxboard used for set-up boxes is made of nonbending chipboard, filled news, solid news, and solid groundwood pulpboard. Boards of this type may be lined on one or both sides and pasted together to produce greater thicknesses.

Even heavier are wet-machine boards, which are too thick to wrap around the dryer rolls in the papermaking machine and, thus, removed with a high moisture content. This heavy-weight board is used mostly for such things as book bindings and shoe boards.

At the premium end of the boxboard grades is solid bleached sulfate (SBS) for use when a 100 percent bleached kraft board is necessary or desirable for high quality graphics and smoothness. There is even a cast-coated SBS that is dried under pressure against a polished cylinder to produce a

TABLE 2.13. Gauges and Densities of Pasted Solid Newsboard (Nonbending).

Regular No. 50-lb Bundle Quantity	Finish Rough in.	Smooth in.	Weight per M ft^2 lb	Weight M Sheets 25 40 lb
10	.233	.196	720	5000
15	.156	.130	480	3333
20	.117	.098	360	2500
25	.094	.078	288	2000
30	.078	.065	240	1667
35	.066	.056	206	1429

Source: American Forest and Paper Association, Washington, D.C.

TABLE 2.14. Relative Costs of Different Boxboard.

Boxboard	Cost/Ton
White Lined Recycled, .020, 60 Bright	$500
White Lined Recycled, .020, 70 Bright	$515
Machine Clay-coated Recycled, .020, 80 Bright	$600
Machine Clay-coated Recycled, .016, 80 Bright	$620
Solid Bleached Kraft, coated, .015, 80 Bright	$850
Unbleached kraft, coated, .020, 80 Bright	$730
Chipboard, Bending, 20-point	$420
Containerboard	
42# Fourdrinier Kraft Linerboard	$400
26# .009 Semichemical Medium	$350

Source: Adapted from *Pulp & Paper Week,* April 1996, Miller Freeman, Inc., San Francisco.

high-gloss enamel finish. SBS is widely used for ethical-drug and medical-product cartons, fancy toiletry and cosmetic items, and many foods such as butter cartons, bacon wrappers, and frozen food packages where the board's coated surface makes direct contact with the food. This type of boxboard also is chosen for high-speed machines where a strong board can provide more consistent performance.

Sometimes called bleached kraft, SBS is higher priced than other boxboards (see Table 2.14). Cast-coated SBS is even more expensive. But because of superior strength, SBS boards can be used in lighter calipers, as a rule of thumb, 2 points (51 m) lighter than bending chipboard to give the same performance. With SBS, scores hold up well with aging, and there is less creep or fatigue under compression.

One way to decrease the cost of such materials and yet retain most of the advantages is with low- and ultra-low-density boards, which have less fibre but have been structured on the paper machine to retain strength and appearance. In fact, ultra-low-density board with 80 percent of the weight of regular-density retains 88 percent of its stiffness. On the down side, folding cartons made from solid board have a greater tendency to bulge.

References

1. American Forest and Paper Association. 1995. *Capacity Survey.*

2. Noel DeKing, News Editor, *Pulp & Paper Week,* private communication, April 1996.

3. American Forest and Paper Association. 1991. *Capacity Survey.*

4. Stone Container Corp. Undated. The Bag Packaging Workshop Manual, p. 25.

Chapter 3— Films and Foils

Introduction

The fastest growing area of packaging, without question, is flexible packaging, a trend which promises to continue into the early 2000s. Flexible structures meet the three most important requirements for packaging, today: (1) favorable reception by consumers, who perceive them to occupy less space in waste-disposal containers and landfills; (2) significant "source reduction" (reduced amount of material) for packagers, minimizing weight, cost, and storage and transport size; and (3) readily tailorable to provide only the needed functional properties required by each product.

Before discussing these useful materials, however, some definitions are in order. First is the differentiation between the terms "film" and "sheet." A plastic material up to 0.010 in. (0.25 mm) in thickness is generally considered a film, above this thickness, it is called sheet (which will be discussed in Chapter 8, Plastics). Film thicknesses also are described in mils, which are equivalent to thousandths of an inch. Hence 0.010 in. equals 10 mils.

Still another way to measure film is by gauge. For example, 48-ga., which is equivalent to 0.48 mil or 0.00048 in. (12.3 μm) is a common thickness for polyethylene terephthalate (PET) film. In fact, some people reserve this measurement for thinner structures. If the film thickness is less than 1 mil, it's specified according to gauge; if it's greater than 1 mil, it's designated in mils. It should be noted that gauge often is used as a generic term for thickness.

When two or more discrete films are combined by means of heat and/or adhesive, the resulting structure is called a laminate. But if the layers are extruded as they are combined, it is termed a coextrusion. Multilayer materials made by either process also are known as composite structures. (See Chapter 4, Coatings and Laminations for more information on multilayer structures).

The thickness of a film is usually specified in mils, (a mil is 0.001 in., 0.0254 mm, or 25.6 m). Gauge numbers also are used; thus, 200-gauge film has a thickness of 2 mils (51.2 m).

Cellophane weights are commonly designated by yield or gauge numbers; for example, a No. 195 (195-gauge) film will provide 19,500 in.^{2}/lb . mil (1,091 m^2/kg mm). For yields of common flexible materials, see Table 3.1.

The United States manufactured and imported about 7 billion lb. (3.18 billion kg) of flexible packaging materials in 1994, a number expected to grow at a rate of about 2.5 percent per year through 1998 (see Table 3.2). This sizable market was worth about $14.7 billion in 1994 [1]. Food applications account for 70 percent of the volume with snack foods representing the largest share (see Table 3.3) [2].

There are nearly 200 companies that produce films and/or coat and laminate films, papers, and foils, and about 300 converters that slit, print, and decorate the materials.

While polyethylene (PE) accounts by far for the greatest volume of plastics used in packaging, the most rapid growth is in polypropylene (PP) film, which is sometimes called the cellophane of the 1990s (see Table 3.4). Plastic materials will continue to dominate flexible packaging at 73 percent, and food packaging, currently about 70 percent of applications, will continue to dominate and grow at a faster rate than nonfood packaging [3].

This chapter will discuss how films and foils are created and the methods used to modify the properties of these materials. Details of the structures and applications of both common and specialty films and flexible constructions will demonstrate the capabilities of modern flexible packaging.

Film Production Methods

Flat-Die and Blown-Film Extrusion

The methods selected to fabricate films depend on the characteristics of the resin and the properties desired. For example, resins can be extruded from a flat, slit die over a chilled roll or into a cold-water bath, both of which provide better clarity since the rapid cooling prevents formation of crystals and spherulites that give films a cloudy appearance. Following flat-die extrusion, a hot film can be oriented in either the machine and/or the crossmachine (transverse) direction.

Film also can be extruded from a circular die, formed into a tube and blown up with air—like an elongated balloon—to expand and thin the film

TABLE 3.1. Flexible Packaging Yields and Costs (1 mil).

Material	Specific Gravity (g/cm^3)	Yield ($in.^2/lb.$)	[m^2/kg]	Cost/lb. ($)	Cost/1,000 $in.^2$ ($)
Aluminum Foil	2.700	10,250	574	1.70	0.166
Cellophane Nitrocellulose	1.500	19,500	1,091	2.80	0.144
Cellophane Polymer	1.500	19,500	1,091	3.26	0.167
Ionomer	0.940	29,440	1,648	1.50	0.051
Nylon 6	1.130	24,500	1,372	2.50	0.102
Nylon 6 Biax.	1.160	24,100	1,349	3.19	0.132
Nylon 6,6	1.130	24,494	1,371	2.50	0.102
Polyester, Oriented	1.400	23,400	1,310	2.40	0.103
Polyethylene, LDPE	0.920	30,000	1,684	0.70	0.023
Polyethylene, LLDPE	0.918	30,150	1,688	0.69	0.023
Polyethylene, HDPE	0.940	29,200	1,635	1.00	0.036
Polypropylene, Oriented	0.905	30,600	1,713	1.10	0.040
Polystyrene, Oriented	1.050	26,400	1,478	1.32	0.050
Polyvinyl Chloride, Flexible	1.230	22,400	1,254	1,00	0.045
Pouch Paper, 25 lb.	0.749	17,280	968	0.52	0.030

Note: Film prices vary widely due to manufacturing processes, functional additives, and converting steps. This table of “budget prices” is for natural film resins without additives, 30-in.-wide flat extrusion into 1-mil films for single truckload quantities.

TABLE 3.2. U.S. Demand for Converted Flexible Packaging (million pounds).

				Percent Annual Growth	
Item	1983	1993	1998	93/98	98/93
By Material					
Plastic	2,200	3,935	4,628	6.0	3.3
Paper	1,340	1,440	1,470	1.2	1.0
Foil	205	230	242	1.2	1.0
Total Demand	3,745	5,605	6,340	4.1	2.5

Source: Adapted from The Freedonia Group, Cleveland, Ohio.

TABLE 3.3. Flexible Packaging Usage by Market Segment.

Food		70%
Snacks	17%	
Confection	10%	
Meat	7%	
Cookies	6%	
Cheese	4%	
Frozen food	4%	
Other	22%	
Nonfood		30%
Medical	8%	
Other	22%	

Source: Adapted from Kline & Co., Fairfield, New Jersey.

TABLE 3.4. Common Plastics Used in Converted Flexible Packaging (million pounds).

Resin	1993	Percent	1998
Polyethylene	2,459	63	2,872
Polypropylene	718	18	900
Polyvinyl Chloride	245	6	275
Polyester	135	3	165
Polyvinyliden Chloride	90	2	98
Polystyrene	85	2	100
Nylon (Polyamide)	82	2	100
Cellophane	80	2	70
Ethylene Vinyl Alcohol	16	.4	26
Other Resins	25	.6	22
TOTAL	3,935		4,628

Source: Adapted from The Freedonia Group, Cleveland, Ohio.

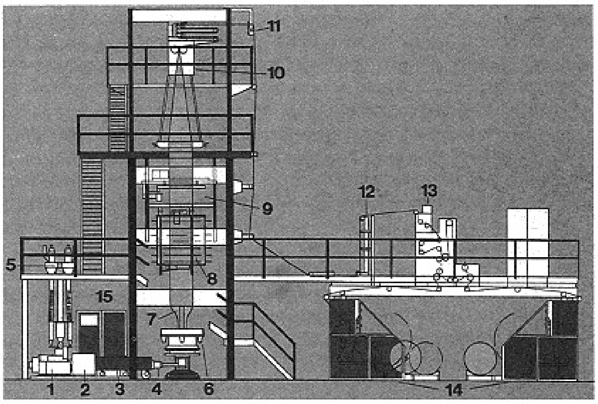

Figure 3.1.
Blown tubular film is extruded upward from a circular die (6). Internal air pressure expands the tube while it is still hot. It then cools (7) as it rises through a film sizing section (8) to an oscillating haul-off and bubble collapsing unit (10). The film then descends and moves through an edge guide control (12) and pretreater (13) to the winding station (14). For flat film, the tube is simply slit and separated. Diameter of the die, thickness of the die slot, take-up speed of the film, and air pressure in the tube can be varied to determine final thickness and orientation. The extrusion die also oscillates or rotates to distribute variations in thickness and avoid high spots in the film roll. (Source: "Varex Blown Film Lines" brochure. Copyright 1992, Windmoeller & Hoelscher Corp., Lengerich, Germany. Reprinted with permission.)

walls (see Figure 3.1). The die is rotated to even out plastic distribution. The tube can then be slit to form a flat film. The film also can be oriented in this process. The blowing process can significantly change the properties of a material. For properties of common films, see Table 3.5.

Calendared films are formed by squeezing a quantity of molten plastic between two nip rolls and a series of heated rollers, resulting in an exceptionally uniform gauge and dimensional stability.

Some resins are cast from solvent suspension onto a polished steel belt. After the solvents are evaporated with heat, the finished film is stripped from the conveyor. While expensive, this process can be used to impart a surface finish such as embossing and is used for resins that are otherwise difficult to film-form.

TABLE 3.5. Properties of Common Monolithic Films.

		Gas Permeation						
Material	WVTR	O^2	N	CO_2	Water Absorb.	Dust Attract.	Haze %	Gloss
Cellophane Nitrocellulose	0.3	1	1	1.4	High	Low	1	,95
Cellophane Polymer	0.5	0.5	0.5	0.5	High	Low	1	90
Fluoropolymer	0.02	7	1	14	Low	High	<1	60
Ionomer	2	450	NA	NA	Med.	High	1-15	45
Nylon 6	18	2.6	NA	NA	High	Med.	4.5	NA
Nylon 6 Biax.	17	1.2	0.7	90	High	High	3	20
Polyester Oriented	0.1	6	1.6	31	Med.	Med.	1.3	NA
LDPE	1.5	420	130	3,277	Low	High	6	75
LLDPE	2	600	NA	NA	Low	High	6	75
HDPE	0.4	150	41	585	Low	High	3	78
OPP	0.35	120	60	360	Low	High	3	85
OPS	11	350	60	1,000	Low	High	1	150
PVC, flex.	30	600	29	618	Low	High	1	150

TABLE 3.5. (continued).

Material	Trans-parency (%)	Printability	Service Temp. F	Sealing Temp. F	Elong. %	Tensile Strength (psi) TD	MD	Tear Strength Elmendorf (g/mil)
Cellophane nitro	95	E	24-300	225	20	9000	18000	8
Cellophane polymer	90	E	24-300	250	20	8000	18000	8
Fluoropolymer	95	NA	-	420	100	7000	12000	-
Ionomer	85	NA	-150-150	225-300	600	3500	5000	40
Nylon 6	NA	NA	-50-250	410-420	400	10000	12000	NA
Nylon 6 Biax.	88	NA	-75-265	410-420	90	28000	32000	8

TABLE 3.5. (continued).

Material	Trans-parency (%)	Printability	Service Temp. F	Sealing Temp. F	Elong. %	Tensile Strength (psi) TD	MD	Tear Strength Elmendorf (g/mil)
Polyester Oriented	88	G	-100-300	275-350	70	32000	39000	20
LDPE	65	F-G	-70-180	250	200	1500	5000	200
LLDPE	65	F-G	-20-220	220-340	400	3000	8000	-
HDPE	NA	F	-40-250	275-310	200	2500	6000	300
OPP	80	E	40-250	200-300	270	20000	30000	340
OPS	92	E	-80-175	250-350	20	8000	12000	15
PVC, flex.	90	E	-20-150	280-340	250	4000	8000	400

g loss/24 hr./100 in.^{2}/mil @ 95 F, 90% RH.

cc/24 hr./100 in.^{2}/mil @ 77 F, 50% RH.

Gardner 60 .

Not measurable because of internal film reflectance

comparison with glass @ 92%.

Transverse and machine directions in psi.

Elmendorf g/mil, notched film.

E = Excellent, G = Good, F = Fair, NA = Not Available/Not Applicable.

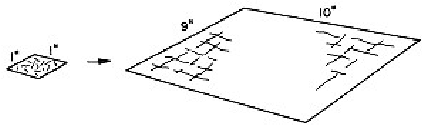

Figure 3.2.
Orientation changes polystyrene film from brittle to tough and flexible. The random arrangement of molecules, shown at the left, becomes more orderly and parallel to the film surface.

Orientation and Cross-linking

Certain properties can be improved by "orienting," or stretching the film under carefully controlled temperatures. This causes a realignment of molecules and yields a much tougher film (see Figures 3.2 and 3.3). Often, it also increases strength and barrier properties. For films produced by flat-die extrusion, the film is stretched in one or two directions by means of a "tentering frame," a device that grips the edges of the web in clamps that are cammed outward to stretch the sheet in the cross-machine direction (Figure 3.4). The largest tentering frame in the world currently is 10 meters (32.8 ft) in width [4]. Stretching in the machine direction is accomplished by increasing the film-winding tension. When the stretching is close to equal in both directions, the film is said to have a balanced orientation.

All blown film has at least a small amount of orientation in both directions by virtue of the way it is produced. This will cause shrinkage unless the film is heat-set after it is blown.

Another method of changing film properties is by cross-linking the poly-

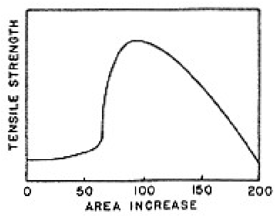

Figure 3.3.
When orienting polystyrene, there is little change in tensile strength at first, but then a sharp improvement. This peaks at a ninety-fold increase in area and falls off as the film is stretched further.

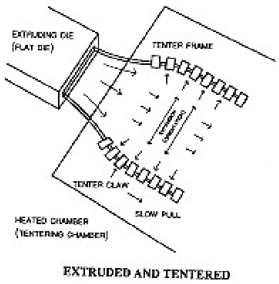

Figure 3.4.
For biaxial orientation, hot, soft film exiting the extruding die is pulled through a tentering frame where fingers grip and gently stretch it in the transverse direction. (Source: Uniflex Corp., Anaheim Hills, California, used with permission)

mers by radiation or chemical treatment to create a material of substantially greater strength and barrier properties. Radiation treatment has been used for many years in the production of shrink film such as that used for frozen meats and fowl.

Radiation also is used to sterilize the inner surfaces of completed packages, mostly for medical and surgical products. Since radiation exposure, especially at higher doses, can have a deteriorative effect (see Table 3.6), packaging materials must be carefully selected. To expand the number of alternatives, suppliers have developed a number of polymers with improved radiation resistance in recent years.

Shrink Films

Mechanical orientation, as described above, creates a film that can be shrunk by subsequent application of heat for uses such as banding (see Chapter 13, Caps and Seals), labeling (see Chapter 12, Labeling and Decorating), bundling, and wrapping.

In the shrink-packaging process, film placed loosely around the article(s) to be packaged shrinks as the product/package passes through a heat tunnel (oven). In the tunnel, the film softens, causing it to seek its original, smaller dimensions and, in the process, to snug tightly around the contents. This ability of a film to draw down over the contents of a package when it is heated is a very useful attribute. Not only does it make an eye-appealing unit for display, but it can immobilize components, making them more se-

TABLE 3.6. Packaging Materials Permitted for Irradiation.

Dosage Maximum (kGy)	
0.5	Paper, kraft, rosin coated
10	Cellophane, coated
	Paper, glassine
	Paperboard, wax coated
	PET films, coated
	Polystyrene
	Nylon 11
	Vinylidene chloride-vinyl chloride copolymer films
30	Ethylene-vinyl acetate copolymers
60	Acrylonitrile copolymers
	Nylon 6 films, coated
	Polyethylene film
	PET films, coated
	Vegetable cellulose parchments

Note: Allowable coatings are listed in CFR 21, Part 179, Subpart C—Packaging Materials for Irradiated Foods. Note also that some materials may be subject to yellowing or browning, odor emission, embrittlement, or reduced strength from irradiation.

cure during handling and provide tamper evidence. For this reason, the process is used extensively in the packaging of consumer and industrial products and also in the stabilization and containment of pallet loads, although the latter has decreased considerably with the development of stretch wrapping. Films used for shrink wrapping are described in Table 3.7 [5].

The required thickness of the film will depend upon the size and weight of the item being packaged, but is most often in the range of 0.5 to 1 mil (12.8 to 25.6 μm) for small consumer products and somewhat thicker for heavy industrial applications. Film can be purchased folded in half on the roll (center-folded) so that only three sides need to be sealed after the product is placed between the two layers. Sealing with a hot wire or heated cutting bar creates a trim-seal that is neat and almost invisible after shrinking. Unless a contoured seal is made, however, these packages tend to have “ears” at acute corners. Depending on product configuration, some films can now be selected that minimize these ears.

With heavier products, impulse-type bar sealers can be used with shrink films to make powerful seals but do not trim off the excess film. With any

TABLE 3.7. Typical Shrink Film Properties.

Film Type	Tensile Strength [psi (MPa)]	Elongation (%)	Tear Strength [g/mil (mN/m)]	Maximum Shrink (%)	Shrink Tension psi (MPa)	Film Shrink temp. [F (C)]
LDPE	9,000	120	8	80	250-400	150-250
	(62)		(3.1)		(1.7-2.8)	(65-120)
LDPE	8,000-13,000	115	5-10	80	400	170-250
	(55-90)		(1.9-3.9)		(2.8)	(75-120)
PE	19,000	130	7	50	450	180-260
	(131)		(2.7)		(3.1)	(85-125)
PP	26,000	50-100	5	80	600	250-330
	(179)		(1.9)		(4.1)	(120-165)
POLYESTER	30,000	130	10-60	55	700-1500	170-300
	(207)		(3.9-23.2)		(4.8-10.3)	(75-150)
PVC	9,000-14,000	140	Variable	60	150-300	150-300
	(62-97)				(1-2.1)	(65-150)

Source: "Films, Shrink," Marilyn Bakker, Editor, *The Wiley Encyclopedia of Packaging Technology*.

type of sealer, the least amount of heat that will do the job makes the best seal (see Figure 3.5).

"Sleeve packing" in which the film is wrapped around the product, extending beyond and leaving ends open is easier to mechanize because only one transverse or longitudinal edge needs to be sealed. When the extended film at the ends shrinks down, it leaves smaller, circular openings that may allow the entry of dust, but also make for easier opening and can serve as "handles" to carry a product, as in the case of shrink-wrapped cases of beverages.

Unbalanced shrinkage is good for sleeve packing and also for flat packages. Bulky items, which are almost as thick as they are long, however, require a more balanced film, which shrinks in both directions almost equally. When film is wrapped around the package, it should be fairly snug so that minimum shrinkage is necessary to pull it tight. If shrinkage can be kept to 10 to 15 percent of potential shrinkability, the loss of tensile strength will be less than 20 percent. Film relaxation with time also will be minimized and may be offset by further shrinkage during storage (see Table 3.8 and Figure 3.6).

Pallet wraps can be made with flat shrink film or preformed bags that are pulled down over the load either manually or automatically and then shrunk to a tight fit in a heated chamber. If "wing pallets" (pallets with deck boards that extend beyond the stringers) are used, the film bag may be pulled down below the wings, which catch the open film ends on shrinking and add compression and even more stability to the load. A bottom film slip sheet also may be laid on these pallets before the load is stacked. Upon shrinking, the bottom film and bag tend to weld together, creating a virtually waterproof "package" that can be stored outdoors.

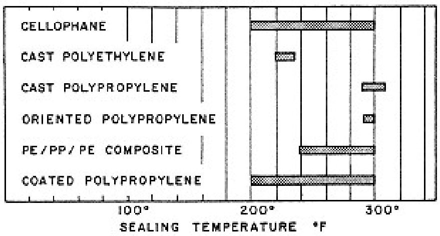

Figure 3.5.
Heat-sealing temperature ranges vary considerably depending on the material itself, as well as coatings and coextruded or laminated plies.

TABLE 3.8. Shrink Films, Performance Comparisons.

Film Type	Advantage	Possible Problems
LDPE	Strong heat seals Low-temperature shrink Medium shrink force for broad application Lowest cost	Narrow shrink temperature range Low stiffness Poorer opticals Sealing wire contamination
PP	Good optical appearance High stiffness High shrink force No heat-sealing fumes Good durability	High shrink temperature High shrink force, not suitable for delicate or fragile products Brittle seals High sealing temperature
Copolymers	Strong heat seals Good optical appearance High shrink force No heat sealing vapors	High shrink force, not suitable for fragile products Higher shrink temperature Higher heat-seal temperature Lower film slip-may give machine problems
PVC	Lowest shrink temperature range Wide shrink temperature range Excellent optical appearance Controlled stiffness by plasticizer content control Lowest shrink force for wrapping fragile products	Weakest heat seals Least durable after plasticizer loss Toxic and corrosive gas emission from heat sealing, good ventilation required Durability problems at low temperature Low shrink force inhibits use as a multiple-unit bundling film Low film slip causes machine wrapping difficulties
Multi-layer Coex	Excellent optical appearance Good machinability Low shrink temperature	In coextruded films, one ply compensates for the deficiencies of the other. As a result, they are superior films with no significant performance shortcomings. The wide variability in layer composition and number of layers makes performance analysis difficult.

Source: "Films, Shrink," Marilyn Bakker, Editor, *The Wiley Encyclopedia of Packaging Technology*. Copyright 1986. Reprinted by permission of John Wiley & Sons, Inc., New York.

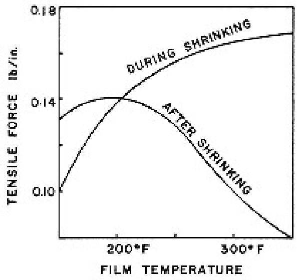

Figure 3.6.
Shrink film tightness is dependent to some extent on the temperature used for shrinking. If it is too hot, the initial tension will be high but will not stand up in storage and handling.

Stretch Films

Stretch films were first introduced in Sweden in 1973 and the process has, to a large extent, replaced shrink wrapping for palletized unit loads everywhere. Stretch film stabilizes a load by means of its elastic properties when the packager stretches it around the goods. It is somewhat better than shrink film because of its elastic recovery, which can adjust to a shifting or shrinking load. It is primarily used for pallet-load wrapping although it also can be used for bundling and wrapping long, narrow items and for labeling.

Polyvinyl chloride (PVC) film was the first stretch material used in the United States but has the disadvantage of retaining only half of its stretch force, as compared with two-thirds for polyolefin films (members of the ethane-methane-butane family of plastics).

The creation of a stretch film is polymeric rather than mechanical. Both blown and cast films are used for stretch wrapping. However, cast film is cooled rapidly by chilled rolls while blown film is cooled more slowly by air. The basic differences in the processes give cast films more uniform gauge, better cling, and stronger linear orientation and tensile strength in the machine direction. Cast films also are stronger in the cross-machine direction for improved tear resistance.

Today, linear-low-density polyethylene (LLDPE) film is the most widely used, followed by PVC; ethylene vinyl acetate (EVA), sometimes with higher than normal VA content; some PP copolymers; and low-density polyethylene (LDPE). These films have high elasticity and low relaxation, very high elongation and high tensile strength in the machine direction, high resistance to

TABLE 3.9. Stretch Wrap Production Speeds.

System Speed	# of Wraps	Wrap Time	Loads per Hour
8 rpm (low)	8	114	31
8 rpm (low)	10	129	28
8 rpm (low)	12	144	25
8 rpm (low)	14	159	22
12 rpm (medium)	8	70	51
12 rpm (medium)	10	80	45
12 rpm (medium)	12	90	40
12 rpm (medium)	14	100	36
15 rpm (high)	8	62	58
15 rpm (high)	10	70	51
15 rpm (high)	12	78	46
15 rpm (high)	14	86	42

Wrap time in seconds includes infeed (loading), wrapping, cut/clamp/wipedown and exit (unloading).

Source: "Myths and Facts about Semiautomatic and Automated Stretch Wrapping Systems," company brochure, Lantech, Inc., Louisville, Kentucky. Copyright 1995. Reprinted with permission.

tearing, and good cling. To achieve these properties, tackifiers, cling additives, and antistatic and anti-block agents are added. Ultraviolet (UV) inhibitors protect films destined for outdoor load storage and colors can be added to films for load identification or masking, a technique used to conceal the nature of the products inside and, thus, reduce pilferage in distribution and storage.

Coextrusions, typically with three layers, but possibly as many as seven, dominate the stretch-film field and allow options such as one-side cling film and materials targeted for niche applications such as frozen food. A special type of stretch film called Fric [6], for example, is a two- or three-layer blown coextrusion of LDPE where an additive in the outer layer explodes like popcorn to form rough hard ridges, which provide a textured nonskid surface in frosty environments. The see-through film is a lighter and less costly alternative to pallet boxes or corrugated pallet wraps.

New base films and additives also have significantly increased strength, permitting the use of thinner gauges. In the beginning, films of 100 gauge (1 mil, 25.6 m) were used. Today, 80-gauge (20.5 m) is standard, and 50-gauge (12.8 m) is increasingly common. Wrapping speeds are faster, too. Depending on the number of wraps and the machine used, it's possible to wrap more than 50 loads per hour (Table 3.9) [7].

There are three methods of applying the film: (1) straight wrapping for several turns with full-width material; (2) spiral winding, in which narrow-width film is applied obliquely in several layers with about 33 percent overlap; and (3) pass-through or dual-roll single-wrap, which is the oldest method and still used for some high-volume, standard-sized loads (see Figure 3.7). By far the greatest number of applications use the narrow-web spiral wrapping technique. With a top-film covering, applied before the body film and trapped by its overlapping turns, a good degree of moisture resistance is attained with this method of unit-load containment.

With the first two application methods, the load is positioned on a rotating turntable while the film feed remains stationary, or it stays still while the film applicator revolves around it. The latter protects lightweight or unstable loads. A top cover film can be applied automatically or manually with these wrapping methods, too.

In practice, the end of the roll-film sheet is attached to the load by tucking it between cases, by film cling, or by taping, gluing, or mechanical attachment. The film is then wrapped around the load in two or more layers, holding the unwrapping of the film roll under tension so that the film is forced to stretch as it is wound around the load. The final cut-off end is then simply wiped down, if there is sufficient cling in the film or attached with the methods described above.

An advantage of stretch wrapping is that it can be applied manually with a tensioning hand device for limited outputs. In high-volume automatic applications, today, the film generally is prestretched by means of powered rollers

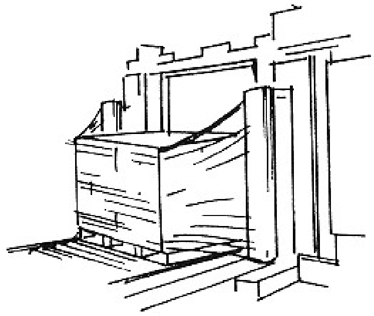

Figure 3.7.
In pass-through stretch wrapping, the pallet is pushed through a curtain of heat-sealed film fed from vertically mounted rolls. As the load moves, the film stretches and is wrapped and heat-sealed around the trailing side of the pallet. Typically used in highspeed, highly automated applications, pass-through machines are becoming less common as conveyorized automatic prestretch machines gain market share. (Source: Paragon Films, Inc., Broken Arrow, OK. Copyright Tom Plant. Reprinted with permission.)

of differential speed located between the film-roll unwind and the pallet load (see Figure 3.8) [8]. Prestretches of up to 300 percent are achieved with this equipment. This not only protects light loads from being pulled out of alignment or fragile loads from being crushed by too much direct stretching force, but also provides higher film yields, more uniform stretch, less neckdown, and greater control of stretch-wrapping forces.

A more recent and growing use for stretch film is bundling where it serves as an alternative to shrink wrap, kraft paper, plastic strapping, or corrugated. Typically, the film is wound around the groups of product or packages as they are conveyed through an orbital wrapper or ring.

While stretch film normally costs more per pound than shrink film, stretch wrapping does not require power for heating. Also, a single width and type of film can handle many different products and configurations, reducing changeover time and film inventory.

It should be noted that both stretch and shrink films are not immune to current resistance by states and local communities to packaging and its supposed excess share of landfill capacity. This subject is covered in Chapter 21, Packaging and the Environment. Suffice it to say here that, as with many

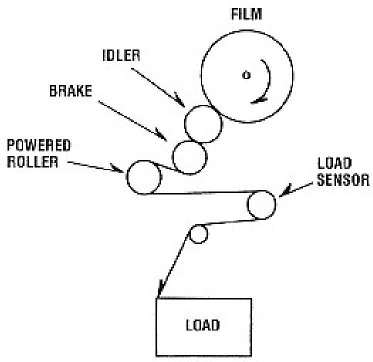

Figure 3.8.
Prestretching film through a group of rollers can increase yield as much as 300 percent. In powered prestretch, the first roller has a brake on top to govern rotation speed, and the second is driven by a motor at constant speed. A third roller allows the operator to adjust the amount of force to the load. Prestretching also can be done mechanically via fixed ratio gearing of a pair of rollers. (Source: From Paragon Films, Inc., Broken Arrow, OK. Copyright Tom Plant. Reprinted with permission.)

other packaging materials, industry has initiated large-scale recycling efforts for shrink and stretch films.

Stretch Netting

Another solution to load and product containment is polyolefin netting. Elastic or stiff in nature, the thin, interconnected strands reduce the amount of plastic used; hence, the netting is more disposable but, generally, also more expensive than stretch or shrink films. The elastic netting conforms well to many awkward shapes and has long been used in tubular form to enclose consumer quantities of fresh produce. A more rigid tubular product often sleeves machine parts to prevent them from being scratched or dinged in handling and shipment.

Netting for the containment of unit loads is wound in rolls and can be applied by standard stretch-wrapping machines. One variety has elastic fibers that maintain a constant and continuing tension around the loads. The other variety is elastic only in the tensioning of the crisscrossed fibers, which must be pulled tight initially to hold the load together. Netting is generally secured with mechanical clamps. Unit-load netting usually is used only for products that require cooling or chilling after packaging or which respire during shipment.

Common Packaging Films and Uses

The volume films are the stars of packaging today. We will discuss them, basically, in their order of use in U.S. packaging.

Polyethylene

Polyethylene was discovered in England in the early 1930s and reached commercial importance during World War II. The earliest films, produced in 1945, were not very transparent, were subject to stress cracking, and were difficult to print and heat-seal. As improvements were made and cost was reduced, the market expanded. By 1956 the price of 1.5-mil (38.4- m) PE film was competitive with that of 195-gauge cellophane, and there was greatly increased activity in adapting wrapping machinery and printing techniques to accommodate the new material.

In wrapping equipment, temperatures had to be controlled more closely, the film had to be pulled instead of pushed because it lacked the stiffness of cellophane; hot plates had to be replaced with bands and bars, the surfaces of which required coating with Teflon to prevent sticking, and static eliminators were invented to prevent film from clinging to itself and machine surfaces. It was not until wrappers were almost completely redesigned that good efficiency was achieved.

It was worth the work, though, because LDPE film offered a whole new set of properties that increased its usefulness far beyond that of cellophane. New sealing methods such as hot-wire cutoffs were developed. Stretch, shrink, blister, and skin packaging and thermoforming all became possible with the advent of this and successive thermoplastic films. Wicketed, rolled, contoured, and side-weld bags were introduced. Soft packages with ponytails and chubs secured with metal clips became practical.

In 1995 U.S. use of LDPE, LLDPE, and high-density polyethylene (HDPE) films grew to an estimated 5.5 billion lb (2.5 billion kg). This included about 180 million lb. (81.6 million kg) of LDPE shrink film and about 205 million lb. (93 million kg) of LDPE and LLDPE stretch films. About half of all PE packaging films are used for foods and half for nonfoods. All of the PEs are cleared for food use by both the federal Food and Drug Administration (FDA), Washington, D.C., and the U.S. Department of Agriculture (USDA), also headquartered in Washington.

With densities that run from 0.890 to 0.960, there are literally hundreds of possible PEs. From a practical standpoint, though, we will consider the four major groups of materials most useful in packaging.

LDPE film is soft and flexible, making it ideal for packaging soft food and nonfood goods. Better than half of this packaging plastic is marketed as film. A small amount is made into sheet and the rest is used in coatings (see Chapter 4, Coating and Lamination).

The pleasant feel of an LDPE-film package is a sales advantage. Stretchiness provides very good impact resistance. Transparency varies, but good clarity can be obtained where necessary, at some sacrifice in other properties such as toughness. High-clarity films may be only half as durable as ones formulated for impact strength.

LDPE film is a good moisture barrier, but its gas barrier and barrier to essential oils and flavor constituents is only fair. LDPE is essentially odorless and tasteless, but still should be carefully monitored for food applications. It has good chemical resistance; except to a few oils and greases such as mineral oil and edible oils that will permeate the film and aromatic hydrocarbon chemicals that can cause stress cracking. The surface of LDPE is nonpolar and resists bonding of adhesives and printing inks. Thus, the film must be surface-treated with flame, corona discharge, or halogen processes before printing and for some coating and adhesive applications (see Figures 3.9, 3.10, and 3.11).

The disadvantages of LDPE can be offset by coextrusion techniques, which also are used with many other films. For example, two thin layers of

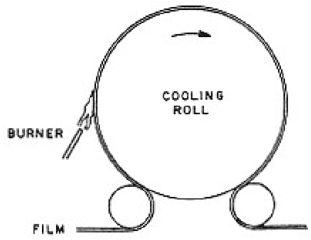

Figure 3.9.
Flame treatment is used to clean and oxidize or polarize the surface of PE film. In action, the 3,600 F (1,982 C) flame contacts one side of the film while a 75 F (23.9 C) cooling roll keeps the other side cool.

LDPE often are extruded with a barrier material in an A-B-A structure in which the PE layers are bonded to a high-barrier material such as polyvinylidene chloride (PVDC). In addition, one PE layer can be pigmented white as a background for surface printing or the film can be reverse-printed before lamination to protect the printing from being scratched in handling and to add gloss from the outer film layer. Similarly, a base PE film can be supplied coated on one side with PVDC for lamination to a number of other films to add strength, barrier, or heat-sealability. This is the reason there are so many

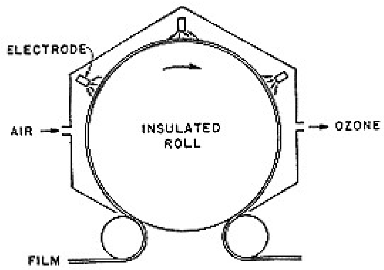

Figure 3.10.
Corona discharge treatment of PE film passes a high-voltage electric current from an electrode to a grounded roller to ionize the air in between and form an arc that cleans and activates the surface of the film.

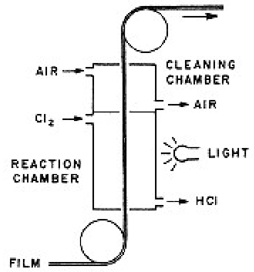

Figure 3.11.
Halogen treatment of PE film with such chemically active gases as chlorine and fluorine oxidizes the surface to change polarity and wettability for adhesion or printing.

film combinations, today. They can be tailored to supply just the requisite properties at the lowest cost.

PE film is available in a number of roll forms that are determined by the type of machine or package construction for which they are intended (see Figure 3.12) and by the location of the printing on the final package and the way in which the machine applies it (see Figure 3.13). Flexography is the usual printing method of choice for film packages because of its economy and its increasingly good quality. Gravure is still used for more delicate and expensive designs, provided the volume is large enough to cover the high cost of gravure printing rolls.

Although LDPE is not as sparkling as some films, the slight haze is not a serious drawback for many consumer and industrial applications where wraps and bags of this very low-cost film are used extensively to package commodity items. Even though gas- and water-vapor barriers are modest, gas transmission rates decrease as the temperature goes down, a fact that enables LDPE to be used extensively for bagging individually quick-frozen vegetables and other foods where its excellent impact strength at freezing temperatures is a great advantage.

While barrier properties often are desirable, permeability also can be a requisite, as in the case of fresh produce, which must breathe or spoil. An example is the precut vegetables packaged on vertical form-fill-seal machines. The film is a rugged PE-based coextrusion with a thin coextruded coating that withholds moisture but transfers gases readily. This multilayer film often adds one or two additional layers for strength and a sealant. The total combination resists both cold temperatures and icing. Still another new film is microperforated mechanically to provide more gas flow for produce with high respiratory rates and to reduce moisture levels inside the package to prevent growth of spoilage organisms.

The tendency of LDPE to block or cling in packaging operations and to collect dust in shelf display can be overcome by incorporation of slip additives and antistatic agents. The physical properties of PE also are influenced by such structural properties as density (see Figure 3.14). With so many conflicting properties from which to choose, packagers should consult with film

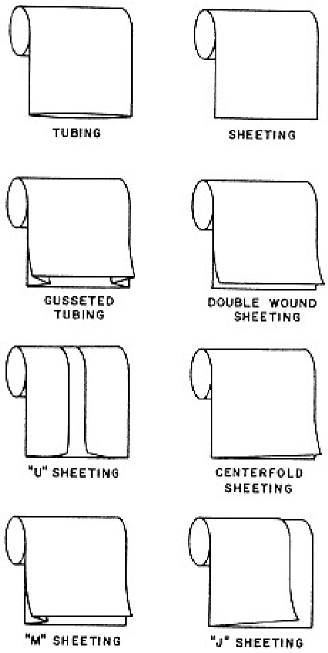

Figure 3.12.
Rollstock film is available in many forms. Tubing is for simple bags sealed at both cut ends. Double-wound sheeting creates double-wall bags secured only at the heat-seals. The slippage between plies greatly adds to bag strength. Folded films in different configurations create bags that can be side-loaded, gusseted, or made with a fold-over lip. Treated surfaces for improved printing and sealing adhesion generally face outside.

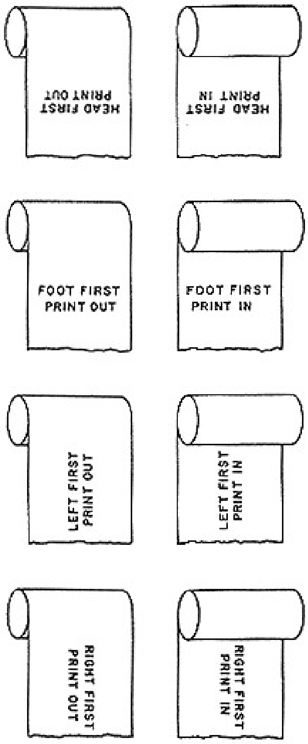

Figure 3.13.
When ordering printed film, direction must be specified along with distance between pattern repeats and location of machine eye spots. Many variations are available to accommodate different packaging machines and finished structures.

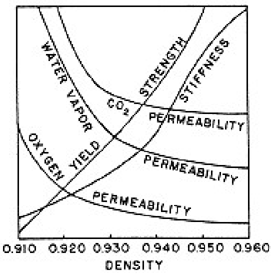

Figure 3.14.
Physical properties of PE materials are governed by molecular structure. Strength and stiffness increase with density, for example, while permeability declines. Note: These curves arranged to show how density affects various properties, are not drawn to a comparable in scale and therefore should not be compared.

manufacturers for guidance in selecting the material best suited for a particular application. More details on the structural and chemical properties of packaging plastics are detailed in Chapter 8, Plastics.

LLDPE, so named because its molecule has less branching than LDPE, is now replacing some lower density applications where economy and increased film toughness, puncture, and tear strength are important. So marked are these advantages that applications using LLDPE often can be considerably downgauged compared to previous LDPE packaging.

This is curious because strength normally increases with density and LLDPE is a relatively low-density polymer. But it is polymerized at low pressures with addition of alpha-olefin comonomers that have the opposite effect from what would be expected. In addition to its strength, ultimate elongation above 600 percent, makes this film well suited to stretch wrapping. As a result, LLDPE is now very much the film of choice over LDPE and EVA. LLDPE also shows up increasingly in a coextruded "sandwich" of EVA/white LLDPE/EVA for frozen vegetables, where the EVA supplies an outstanding heat-seal and the LLDPE provides superior strength and resistance to the abrasiveness of frozen products.

The same goes for LLDPE film bags used extensively in Canada for milk, where polybutylene serves the role of sealant (a cost-effective package that has yet to gain popularity in the United States except for a few school-lunch programs). Foodservice bags for condiments and sauces also have adopted composite LLDPE structures as have industrial bags for chemicals where LLDPE is combined with an LDPE sealant and even an HDPE layer if temperature resistance for hot-filling applications is required. LDPE film softens at 210 F (98.9 C), whereas HDPE softens at 260 F (126.7 C).

Broadening the potential of LLDPE and other olefin plastics even further is a new metallocene-catalyzed polymerization process that increases film clarity, toughness, and extrudability at a relatively small increase in cost. The improved properties reportedly make downgauging in the range of 30 percent possible. A 1-mil mLLDPE film, for example, improves impact strength to 300 g compared to 231 g for traditional hexene-based LLDPE and 131 g for LDPE. Potential markets include fresh produce packaging as well as meat and candy wrap. (See Chapter 8, Plastics for more information on new polymers and processes.)

Medium-density PE (MDPE) is a bit stronger, stiffer, and less permeable than LDPE and, consequently, is sometimes used in film composites where these properties must be enhanced. It is also blended or layered with LDPE for the same reasons.

HDPE is used more in blowmolding and injection molding than in films, but a bit over 300 million lb (136 million kg) was used in 1994 in film packaging, about evenly divided between food and nonfood applications. (The biggest film application, grocery and merchandise bags, is not considered packaging in this Handbook).

It is the stiffest and least clear of the PE films, but also has greater temperature resistance, a lower water-vapor transmission rate (WVTR), greater resistance to difficult chemicals, and greater strength than LDPE or even combinations of LDPE and LLDPE. High-density films are less likely to block, so that slip agents normally are not required. The stiff film is also less stretchy, which makes bags easier to open than with the other PE films.

HDPE has replaced large quantities of glassine and greaseproof papers for the packaging of cereals, crackers, and other snack foods and is used in bag-in-box and shipping-bag structures, where transparency is not a requirement. It could gain even more mileage with new coextruded combinations such as HDPE/nylon/ethylene vinyl alcohol (EVOH), which offers a high degree of strength, toughness, and barrier properties. This base film is then laminated to LDPE or ionomer films to add the requisite heat-sealability and, in the case of the ionomer, even more strength.

Added puncture and tear resistance is possible with a unique structure that cross-laminates at a 45-degree angle two (or multiples thereof) webs of oriented HDPE. This powerful structure is used widely in shipping sacks for abrasive and prickly products and also for very expensive chemicals that cannot afford a bag puncture.

Polypropylen

Polypropylene (PP) is a multipurpose film that has captured broad applications in just a few years. It was created by Professor Giulio Natta and developed by Montecatini of Italy in the late 1950s.

With total usage running to about 773 million lb (350.6 million kg) in 1995, nonoriented (PP) and oriented (OPP) films have truly earned their description as the cellophane of the 1990s. About one-quarter of OPP film is devoted to the giant and growing snack-food field. Baked goods take another chunk and the balance is spread over many products. Nonoriented PP has a foot into food packaging, too, particularly for cheese wraps, but is strong also in such nonfood applications as textiles and medical disposables, where its temperature resistance permits autoclaving.

Nonoriented PP, generally made by chill-roll casting, has great clarity, good moisture barrier, and higher temperature resistance than PE. It also has a soft "hand" (tactile feeling), regarded as a useful marketing tool for soft products. Although not as strong as OPP, it is one of the lowest cost packaging films. PP includes a range of homopolymers, random copolymers, and block polymers (for chemical details see Chapter 8, Plastics).

On the down side, PP embrittles at freezing temperatures and has a relatively poor gas barrier. Its softness makes it unsuitable for application with products that have sharp or pointed profiles. Its heat-seal range is narrow and temperatures must be regulated to prevent "angel hairs" (stringing of molten plastic). Close control also is necessary in extrusion to insure a uniform gauge. Film must be surface treated, as with all polyolefins, to insure adhesion of printing and adhesives, and slip additives are necessary to improve machinability.

OPPs are created from homo-, co-, and terpolymer resins, which also may contain small amounts of terpenes, styrenes, and ethylene and/or butene. Orientation can be accomplished on a tenter frame or by the blown-film process, both of which create films with essentially the same physical properties. Modern production methods create OPP film in a single, continuous process, which includes a heat-set step to stabilize orientation, a corona treatment to oxidize the surface for printing and adhesion, and a final winding into mill rolls of up to 33 feet (10 m) wide. Heat-setting with the tentering method is conducted by heated rollers. These also are used on the collapsed bubble in blown film production, or can be supplanted by a secondary heating and blowing operation of the film bubble. In both orienting processes, the degree of equalized orientation in both film directions can be regulated by the amount of drawdown created by the speed of film windup compared with the size of the bubble or, in tentering, the width of film stretching.

The result is an OPP with great clarity, good moisture-barrier properties, high tensile strength, adequate impact strength. It is also among the lowest cost films because of the inherent low density of the resin and its capability of being drawn into very thin films both for monolithic use or as a component in laminations and coextrusions. Orientation alone greatly increases the cold-temperature resistance of OPP over PP. However, OPP still has a high coefficient of friction, is difficult to seal with other than hot-wire techniques, and lacks a good gas barrier. Better slip has been attained with development of incorporated slip agents that migrate to the surface, greatly improving machinability. Stripes of adhesive on film edges have enabled lap seals on horizontal and vertical form-fill-seal equipment. Incorporation of terpenes in the film widen the sealing range, but lack good heat-seal tack, which limits applications. However, since this film is only partially heat-set, it can be tightened by heat. Acrylic coatings on OPP widen the sealing range and also add sparkle and slip to the film.

Still another approach is to coat OPP with PVDC. A one-side-coated film is laminated or coated with other materials, even OPP for specific applications. It also can be coated with acrylic on the other side for a very sealable and good barrier film with widespread potential for food packaging. The two-side-coated material, which possesses a high gas barrier, is costly, but used in laminations for products that require very strong barriers. Finally, OPP can be coextruded with a variety of plies that overcome its deficiencies or enhance its strengths: PE to supply sealability; ionomers to increase strength and resistance to greases and oils; PVDC or EVOH for high barriers. In fact, a sandwich of OPP with its moisture barrier around a core layer of EVOH, which is sensitive to moisture, vastly improves both materials.

OPP films only slightly thicker than a half mil (12.8 m) are used for very lightweight packaging applications or are laminated to other substrates such as paper, glassine, cellophane, and other films for mutual benefit in both food and nonfood applications.

OPP increasingly is metallized with light coatings for decorative uses, heavier coatings for greatly increased barriers to moisture, gases, and light penetration.

Also more popular are opaque white films that serve as a good background for graphics as well as protection from light degradation. These generally are oriented by tenter frame. If a small amount of mineral agent is added, the orientation creates air-filled closed cells around the particles that refract light to create opacity. If more filler is used, the voids are avoided and opacity becomes more directly proportional to the amount of mineral filler employed. These PP materials are all cleared for food use by the FDA and USDA.

Ethylene Copolymers

Ethylene copolymers are workhorse plastics often overlooked because they tend to be lumped with the PEs and lack the glamour of their more publicized brethren. However, only the PEs and PPs are used in greater volume in the United States.

Ethylene acrylic acid (EAA) and ethylene methylacrylate acid (EMA) are used extensively as sealants or "tie" (adhesive bonding) layers in multilayer films to enhance strength and sealability. EVOH is an important copolymer for improving film barriers to moisture and gas transmission, generally as an inside coating or coextrusion (see Chapter 4, Coating and Lamination).

But the material in greatest volume, which displaces even PE in many applications, is ethylene vinyl acetate copolymer (EVA). It can be either cast or blown. The cast film has greater clarity, but the blown film is tough. A content of about 8 percent vinyl acetate produces a PE-like material, but with better elasticity and heat-seal strength. At vinyl acetate levels of about 20 percent, the resultant material is like plasticized PVC, soft and clingy. As a result, EVA handles a major share of stretch-film applications where its natural tack gives it an advantage over PP and shrink-film pallet bags where its toughness gives superior protection.

In coextrusions and coatings, EVA is paired with many plastics to supply superior film-to-film adherence and heat-seal properties, respectively. A major application is as a two-side sandwich to metallized polyester film for modified-atmosphere bag-in-box constructions that range from consumer sizes to flexible bulk containers holding up to 330 gallons (1,249 L). EVA has largely replaced PE in these applications because of its strength, stress-crack resistance, and superior heat-seals.

For the same reasons, an EVA/PVDC/EVA coextrusion dominates the packaging of primal and subprimal meat cuts for transport from slaughter houses to market. The structure is a shrink film that is tightened around the meat cuts in a hot-water bath to eliminate oxygen content in the package.

Polyvinyl Chloride

PVC was produced in the laboratory in the early part of the last century by Henri Victor Regnault, but was not available as a commercial product until 1927. PVC can be produced as a rigid film or sheet, but is more often plasticized to create a soft, pliable material. Oriented PVC shrink film was developed by Reynolds Metals Co., Richmond, Virginia, in 1959.

Production of PVC packaging films in 1995 is estimated at 255 million lb (115.7 million kg). In addition to film packaging, PVC sheet also is used extensively in thermoformed packaging for a wide range of goods and for medical disposables (see Chapter 8).

Vinyl film without plasticizers is stiff and somewhat brittle. It can be given any degree of softness by adding plasticizers. PVC has excellent clarity and brilliance and is among the lowest priced films.

However, its growth rate is limited because its biggest use is as a low-shrink film for retail tray wrapping of meats, poultry, fish, and produce. In these applications, its moisture and gas transmission properties are ideal: The water barrier retards weight loss while permitting the passage of oxygen to keep the red “bloom” intact in packaged meats and allow respiration in fresh produce. PVC also is resistant to oils and greases and has good toughness. Custom compounding with heat, UV, and radiation stabilizers (such as the octyl tins cleared for food and drug use), impact modifiers, antioxidants, antistats, slip additives, fillers, and colorants are a necessity. For use with foods and drugs, residual vinyl chloride monomer content must be maintained below 10 ppb (parts per billion) to satisfy the FDA and USDA.

The earliest method of producing PVC film was by solvent casting on a polished stainless steel belt because the resin is quite sensitive to heat degradation. However, improvements in both resin and manufacturing methods have made flat- and round-die blown extrusion feasible, although calendering is still a major manufacturing method.

Orientation in one or both directions will improve impact resistance. The moisture and gas barrier properties remain the same when the film is oriented and also when it is put through a shrink tunnel since these characteristics are a function of thickness only. The tensile strength of oriented film is about four times that of cast film of equal thickness and impact strength goes up about ten times. Shrink film can be sensitive to heat and should be stored below 90 F (32 C) to prevent premature shrinkage.

Resistance to oils, greases, and waxes, as well as to petroleum solvents, is good provided the plasticizers or other additives are not extracted by them. Because unpleasant odors sometimes develop from oxidation of the stabilizers, the film should be carefully tested over a period of a week or more before it is used with food products.

Heat in the vicinity of 280 F (138 C) may degrade the film with the release of hydrochloric acid. Sunlight also can have a negative effect, causing yellowing, unless stabilizers are added before the film is extruded. Transparency is exceptionally good, but the surface is easily scratched or abraded. As for cost, generally only the olefins and polystyrene (PS) are cheaper.

Rigid vinyl is resistant to acids and alkalies, except some oxidizing acids. It is not affected by oils, alcohols, and petroleum solvents but is attacked by aromatic hydrocarbons, halogenated hydrocarbons, ketones, aldehydes, esters, aromatic ethers, anhydrides, and molecules containing nitrogen, sulfur, or phosphorus. Oxidizing and reducing agents have no effect; nor does chlorine.

In plasticized PVC, as much as 50 percent of the formulation can be made up of additives. In selecting films for packaging, it is very important to consider the effects of these additives on the stability and compatibility of the contents. Some plasticizers are highly toxic and must not be used with food products. Some will migrate and interact with the product. Therefore, extreme care is necessary in selecting the right formulation, particularly for food and drug products, and an extensive test program under actual conditions of use is strongly recommended.

PVC film can be heat-sealed by hot-wire, impulse, resistance, and dielectric heaters, but heating bars should be protected from the corrosive effects of heated film. The vapors from heat-sealing can be irritating if inhaled. The film can be adhesive- or solvent-sealed quite readily. Shrink films with greater than 50 percent shrink are used for both stretch and shrink packaging. Machinability is good, and slip characteristics are generally satisfactory. Printing inks are usually formulated with vinyl resins, and flexography is the method typically employed, often with an overprint varnish of polyamide resin in an alcohol solvent to add gloss and scuff resistance.

Polyester

Polyester film was a British discovery, purchased by DuPont Co., Wilmington, Delaware, and licensed to Imperial Chemical Industries, Ltd. for manufacture in Europe. The earliest work with this class of compounds is believed to have been done by W. H. Carothers around 1928. This set the stage for the discovery 12 years later of polyethylene terephthalate (PET) by J. R. Whinfield and J. T. Dickson.

PET is a high-performance film and about 145 million lb (65.8 million kg) were used in U.S. packaging in 1995. PET has exceptional tensile strength, over 20,000 psi (lb per in.^{2}) (1,406 kg per cm^2) and a 50 percent elongation over a wide temperature range, giving it good impact strength. Highly suitable for boil-in-bag and bake-in foods, it has good dimensional stability, chemical resistance, toughness, clarity, stiffness, some barrier properties, and usually contains no plasticizers. However, it is rather costly, although this is somewhat offset by its strength, which permits use of thinner gauges. This will be improved with the recent development of a 32-gauge film (0.032 in., 820.5 m), which yields about 50 percent more film per pound than the standard 48-gauge (0.00048 in., 12.3 m) and maintains an excellent tensile strength. It could cut into both OPP and 250K cellophane (polymer-coated) for many snacks, confections, and pharmaceutical applications.

PET has a moderate WVTR, but this drops to near zero at freezing temperatures. Impact resistance is good, but tear and puncture resistance is not as good as that of the softer films, although it's adequate for most packaging applications. The uncoated film is not heat-sealable, but it can be solvent-sealed with an application of benzyl alcohol, heat, and pressure. Hot-wire seals are possible, but tend to be weak and not leakproof. Coextruded and laminated films with the proper coatings can be heat-sealed. Unoriented film is available for lamination, but when it is the main substrate, polyester film usually is oriented.

Orientation is by either the cast-tentered or blown-bubble process. While tentering is more expensive, it produces better gauge control and uniformity. Therefore, most PET film is made by this method. The molten resin is extruded onto a casting drum and stretched in the machine direction. The sheet then passes into a heated multi-zone tunnel and is grasped by the tentering clamps, which pull the film equally in the transverse direction. The final biaxially oriented film is heat-set. Orientation enhances all of PET's properties. To improve them still further, PET is often coated on one or both sides with either PVDC or PE or both. These coatings provide sealability and improve moisture-barrier properties. PET retains its properties from -80 to 300 F (-62 to 149 C) for short periods at the upper limit and indefinitely to 230 F (110 C)

Polystyrene

PS was used as an intermediate for the manufacture of synthetic rubber as early as 1925, but styrene as a packaging plastic did not become available until the 1930s. It has become one of our most useful materials because of its exceptional clarity, reasonable cost, and the number of ways in which it can be formed.

However, while molded PS rigid and foamed-plastic structures are popular in packaging (see Chapter 8, Plastics, for injection-molding and thermoforming applications and Chapter 16, Cushioning), use of PS film is quite limited, about 90 million lb (40.8 million kg) in 1995.

This plastic is naturally very brittle and, until orientation was introduced in 1958, styrene film could be used only in laminations. When stretched under carefully controlled temperatures, the molecules are rearranged to produce a more flexible film. Now, homopolymer styrene film and sheet are available oriented or unoriented, nearly always without plasticizers. Copolymers with acrylics and such rubbers as styrene butadiene are much tougher than the homopolymer, but sacrifice some transparency and add to the material cost. These copolymers are designated in the trade as impact, high-impact, and super-high-impact grades, depending on the proportion of rubber to styrene.

However, the new metallocene technology used for polymer formation (see Chapter 8, Plastics) is said to radically improve the strength of PS sheet and films and to reduce its brittleness, which could well increase the usefulness of this material in packaging applications.

The clarity and sparkle of PS film are outstanding, and its stiffness makes it an easy material to handle on wrapping machines. PS is odorless and tasteless, ages well, does not require special storage, and has good dimensional stability. It readily accepts printing and metallizing and can be reverse-side printed and laminated to "lock in" the decoration, and, thus, take advantage of its high gloss and sparkle. However, heat-sealing is difficult and so adhesives generally are used for making bags and for overwrapping. Of the heat-sealing methods, impulse-type equipment works the best.

Barrier properties for moisture and gases are poor, chemical resistance is very limited, and impact strength is low. Static buildup in dry weather also causes dust to collect on shelved packages. Therefore, PS film use in packaging generally is limited to film wraps for lightweight and quick-turnover produce baskets and some baked goods, where its gas and water-vapor transmission capabilities are appreciated. A much greater amount is used as sheet for thermoformed packaging for some foods and a great number of other retail products because of its sparkling clarity (see Chapter 8, Plastics).

Nylon (Polyamide)

PAs, or nylons, were introduced by DuPont in 1938 and long have been better known as a fiber for woven or knitted fabrics than as a film. But, no longer. While rather high-priced as films go, toughness and high-temperature resistance make nylons useful for an increasing number of packaging applications.

An estimated 88 million lb (39.9 million kg) were used in 1995. Nylons are classified by the number of carbon atoms in the repeating molecule, and can be as simple as nylon-6 or nylon-6/6 in a more complex structure, or even nylon-6/6,6 when different amides are copolymerized. PA films are made by either cast- or blown-film methods and a popular packaging film is biaxially oriented nylon 6 (BON).

Elongation is high, comparable to that of PE, and these materials are resistant to stress-cracking. The films must be corona treated for sealing. It has a sharp melting point and heat-seals between 250 and 350 F (121 and 177 C) with seal strength about 85 percent of the ultimate film strength. Adhesives give joints with about 80 percent of the film strength. Impulse equipment gives the best seals, although constant-heat bars or high-frequency methods can be used.

Biaxial orientation increases tensile strength by almost three-fold and doubles tear strength. It also increases barrier properties and resistance to stress-cracking.

PAs can be coextruded, coated, or adhesively laminated. In multilayer films, PE, EVA, EAA, ionomer, and foil are often the partners. Metallized PA is also growing in use. PA films are a good gas barrier when dry and, thus, often are buried in multilayer structures, since nylons are hygroscopic in nature. The tendency to absorb water is important in processing, since the resin must be very dry to extrude properly. When cast film is rapidly cooled the resultant film is amorphous instead of crystalline, which has a marked effect on properties. Amorphous film is very clear and thermoforms readily.

Nylons are resistant to alkalies and dilute acids but not to strong acids or oxidizing agents. Formic acid and phenol will dissolve nylon and can be used as adhesives. Nylon is tasteless, odorless, and nontoxic. Resistance to sunlight is only fair.

In high-temperature packaging applications, such as autoclaving for medical products, monolithic nylons often are used. Resistant to ethylene oxide sterilization, when modified, they successfully withstand radiation sterilization, as well.

Nylon film has been used by the armed services for packaging spare parts because of its resistance to puncture, abrasion, grease, and solvents. The films are used as wraps for primal cuts of meat for the same reasons. For heavy products or where low moisture vapor transmission is required, nylon is combined by coating or lamination with PE or ionomer films.

Nylon has become an important component in high-barrier ground-coffee bags as the replacement for aluminum foil in a three-layer material composed of polyester on the outside and LLDPE on the inside. The foil could not take abrasion from sharp coffee particles, which were successfully contained by the nylon and also maintained the necessary barrier properties.

Now, there are amorphous polyamides (AMPA), created by adding a ring to the otherwise linear nylon chain, which inhibits crystallization. These materials are less affected by moisture and offer an increased barrier to gases.

Still another new amide is MXDA, a polycondensation product of adipic acid and metaxylylene diamine. It too, is insensitive to moisture and its barrier properties to gas and water-vapor are far higher than those of today's workhorse, nylon 6.

Cellophane

Cellophane was first produced in the laboratory in 1892 and a British patent, which described a method of making thread and film from viscose, was granted to C. H. Stearn in 1898. A Swiss chemist named Jacques E. Brandenberger designed a machine for making continuous film in 1911. He called the product cellophane, from the first half of "cellulose" and the ending of "diaphane," the French word for transparent. DuPont secured the American rights to the Brandenberger process in 1923 and started making the film in Buffalo, New York, in 1924.

The cellophane that was first produced was tacky, brittle, and lumpy, and users complained that cigars dried out and knives rusted when wrapped in the material. A research chemist, Dr. W. Hale Church, was assigned by DuPont in January 1925 to improve the properties of cellophane. He was joined six months later by Karl E. Prindle and others.

By 1927 they had developed a coating made from two incompatible materials—nitrocellulose and paraffin wax—combined with a plasticizer and a blending agent. By means of volatile solvents they were able to deposit 0.05 mil (5 10^{-5} in., 1.3 m) of the coating on both sides of a 1-mil film, which made it moistureproof and heat-sealable. Almost immediately cellophane was a huge success, reaching a worldwide usage of nearly 1.5 billion lb (680 million kg) at its apex. Its scope was widened still further by applying coatings of PVDC or PE to improve barrier properties and strength, at a higher price, of course.

Cellophane has largely been replaced by the polyolefins of the next packaging generations. However, there is a packaging truism that every packaging material ever invented is still in some use for applications for which only it is effective. So it is with cellophane, with 1995 U.S. consumption amounting to more than 50 million lb (22.7 million kg) [9].

Cellophane is regenerated cellulose and quite different from other transparent films. The basic molecule $(C_6H_{10}O_5)_x$ is made up of glucose molecules from which a molecule of water has been removed (see Figure 3.15). It is produced in thirteen gauges ranging from 0.78 to 1.68 mil (20 to 43 m) (see Table 3.10) [10] and is coded by letters that represent its structure and properties (Table 3.11). Cellophane is not thermoplastic and can be heat-sealed only if coated with an appropriate sealant. In the uncoated state, it is

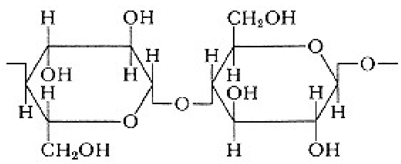

Figure 3.15.
The pyranose ring representation of a cellulose molecule. (See Chapter 8, Plastics for graphic formulas of other packaging plastics.)

TABLE 3.10. Cellophane Types by Gauge.

English Figures			SI Figures		
Gauge (in.^{2}/100 lb)	Coverage (in.^{2}/lb)	Thickness (mils)	Gauge (10 g/m^2)	Coverage (m^2/kg)	Thickness (m)
250	25,000	0.78	280	35.7	20.0:20.0
220	22,000	0.90	320	31.3	23.1
210	21,000	0.93	335	29.9	23.8
207	20,700	0.94	340	29.4	24.1
201	20,100	0.98	350	28.6	25.1
195	19,500	1.00	360	27.8	25.6
180	18,000	1.08	391	25.6	27.7
160	16,000	1.22	440	22.7	31.3
145	14,500	1.40	485	20.6	35.9
140	14,000	1.39	500	35.3	35.6
116	11,600	1.68	600	16.7	43.1

very sensitive to moisture, expanding and contracting as the humidity changes. Tensile and impact strength are excellent, but tear strength is poor. Once a tear starts, it propagates easily.

Cellophane has excellent grease, oil, and oxygen barrier. It also has excellent clarity and sparkle and is available in pigmented varieties. Easily machined, it makes a strong package with good tensile and impact strength. Heat-sealing is not critical for coated cellophane and the temperature can vary by more than 50 F (10 C) and still produce a good bond. When notched, it tears easily, which is both good and bad. For ease in opening by means of a tear tape, cellophane is unsurpassed by virtue of this easy tearing.

TABLE 3.11. Cellophane Code Designations.

A	Vinyl acetate/vinyl chloride coated
B	Anchored (bonded)
C	Colored (also R = red, B = blue, Y = yellow, etc.)
D	Decreased moistureproofness
L	Intermediate moistureproofness
M	Moistureproof
O	One-side coated
P	Plain uncoated
S	Heat-sealable
T	Transparent
V, X, or K	Polymer (PVDC-coated)
W	White opaque

It is a good substrate for coatings and laminations, since it is the only transparent film that does not soften with heat.

On the debit side, cellophane can become shelf-worn (cockle) if handled excessively. It can shrink and get brittle under dry conditions in the winter and the tearing characteristic, which makes packages easy to open, can be a problem in the marketplace if the film edge gets nicked or starts to tear [11].

Controlled permeability is one of the outstanding characteristics of cellophane. It is possible to apply different coatings in different amounts and varied laminations to give cellophane the exact characteristics desired. Most commonly used are PVDC, nitrocellulose, wax, and vinyl acetate/vinyl chloride coatings and laminations of LDPE and OPP for a variety of products that include candies, cheeses, pharmaceuticals, snacks, and dried foods [12]. Metallized cellophane also is growing in use.

Ionomer

Ionomers were discovered by DuPont in the early 1960s with the copolymerization of ethylene with methacrylic acid. The copolymer is similar in nature to PE, but when the acid is neutralized with sodium or zinc, it was discovered that this metallic and ionic phase creates some very useful properties. A number of ionomers have been invented with different metals, but the most important to date from a packaging standpoint are grades dubbed Surlyn by DuPont.

These copolymers have a high tensile strength, are tough and abrasion resistant, form strong heat-seals, and have a high degree of clarity and resistance to oils and greases. The zinc ionomers adhere very well to foils, nylon, and other polyolefins, too. They are flat-die extruded and blown into monolithic films.

The down side is that ionomer films have low slip and tend to block. Therefore, chief applications are in coextrusions and coatings for films, which are then frequently laminated to other films to multiply protective properties. A good example is the laminated film structure polyester/nylon/ionomer, which has considerable usage in the packaging of processed meats and cheeses. Ionomers also are used in skin and thermoformed packaging (see Chapter 8, Plastics).

Polycarbonate

PC was discovered by Dr. Daniel W. Fox in 1953 while working at the Schenectady Research Center of GE Plastics, Pittsfield, Massachusetts, and at about the same time by Farbenfabriken-Bayer AG of Germany. PC's high price has deterred adoption for packaging until recently, but where toughness and a high softening temperature (270 F, 132 C) are required, it serves very well.

PC film can be extruded by cast or blowing methods and has excellent dimensional stability, radiation resistance, rigidity, impact resistance, clarity, and tensile strength without orientation. For processing, PC resin must be absolutely dry otherwise silvery streaks, splays, chicken tracks, or air bubbles may spoil the appearance of the finished package. Even when the material is dry at the start, if it is not protected from the atmosphere, within 10 minutes it can pick up enough moisture to affect production. Not only will the appearance be impaired, but the material will lose toughness and impact strength. Heat-sealing requires temperatures from 400 to 420 F (204 to 216 C). Seal strength is around 10 lb per in. (1.79 kg per cm). Dielectric sealing is not feasible because of the low power factor.

PC's high- and low-temperature resistance has led to packaging uses in retorting and autoclaving for foods and medical products. Thermoformed sheet packages have applications in medical devices and frozen-food trays, while coextruded bottles hold liquid products including foods (see Chapter 8, Plastics). PC is broadly resistant to chemicals of all kinds except alkalies. On the down side, it offers very low barrier to moisture and gas transmission.

As a film, PC coextrusions are being evaluated for packaging elicate snacks where the material's inherent strength provides great product protection. Coextrusions with other resins may allow it to compete, despite its cost, with structures that must bear the cost of orientation to attain strength and stiffness.

Specialty Films

A number of plastic films that do not have broad application in the packaging field are worthy of mention for unusual requirements when a higher cost may be justified if the material solves a difficult packaging problem. They will be discussed in alphabetical order.

Fluoropolymer

Fluoropolymers resemble paraffin in nature, but with the hydrogen atoms replaced by fluorine or chlorine. They can be extruded as films, but the only one with packaging significance is variously tradenamed Aclar or Kel-F. It is a polychlorotrifluoroethylene noted for its high price and for its very low permeation of moisture and gases. It is also inert to most chemicals and to such deteriorative factors as ozone and radiation. It will resist temperature extremes ranging from cryogenic to 300 F (148.9 C) and so, can withstand autoclaving and other sterilizing methods.

The film can be heat-sealed and laminated to a wide variety of papers, films, and foil. It is printable. It has a limited use for such delicate products as medical and military devices, which require the ultimate barrier protection at any price. However, disposal can be a problem since burning this material releases toxic and corrosive halogen gases.

High-Nitrile

High-nitrile films started in the form of an acrylonitrile-styrene copolymer for carbonated beverage bottles that boasted high-barrier properties. FDA concern over extraction into the beverage, however, effectively ended the application even though, 20 years later, the agency approved the product with a limit on extraction of 1 ppm (part per million).

Rubber-modified copolymers of acrylonitrile and methacrylate have been made into film. Such materials are strong and have a gas barrier surpassed only by EVOH and can withstand microwave oven temperatures. The materials have been laminated to foil and the various polyolefins and slow growth is predicted in medical and food applications.

Water-Soluble

There's been a surge in interest in water-soluble film, especially for premeasured packets of ingredients, because it can offer source and cost reduction potential while simplifying handling by increasing measuring accuracy, minimizing dust and contamination, and reducing worker exposure.

Some water-soluble films are “edible.” However, it must be noted that any film that actually will be consumed as part of a food or drug product will always require secondary packaging to protect it from contamination during distribution and storage. A number of researchers have looked at edible films made from various materials including whey protein. Commercial products have been based on polysaccharide or wheat gluten and, more commonly, methyl cellulose.

Methyl Cellulose

Methyl cellulose is a water-soluble and edible film used for premeasured products added to mixes. Since the film will dissolve, it doesn't need to be removed before the product is used. Toxic agricultural herbicides/pesticides, for example, can be added to spray tanks in exact amounts with less hazard to the consumer. Other potential products include detergent powder, medicinal capsules, bubble-bath, food ingredients, and as a transfer medium for decorating molded deserts. The film is printable, can be colored or flavored, and runs on most form-fill-seal equipment. Although soluble in water, the film retains its strength and does not become tacky under humid conditions. It only starts to disintegrate when it comes into contact with liquid water.

Polyvinyl Alcohol

One of the most common water-soluble films, polyvinyl alcohol is used to package dry products such as cleaners, dyes, and agricultural chemicals that are put into water, package and all. It sometimes contains a glycerin plasticizer. Embossing the film or dusting it with starch improves slip characteristics.

It is a tough, transparent material with good ultraviolet light stability and gas barrier properties. It is highly resistant to most chemicals including petroleum solvents, greases, and oils. However, aldehydes interfere with solubility and lower monohydric alcohols produce some solvent or swelling action. When used with detergent powders, the film increases cleaning power by suspending the dirt in solution.

Although it will dissolve in water in roughly a minute, it maintains integrity in humid conditions. However, for optimum machinability, it should be stored in protective packaging under recommended conditions, usually somewhere between 65 and 75 F (18 and 24 C) and 40 to 70 percent RH. The film can be printed with water-soluble inks and is heat-sealable on either side. It also can be solvent sealed with a dilute water solution of polyvinyl alcohol.

"Smart" Structures

"Smart" is the somewhat dramatic term now used to identify a packaging material that senses product requirements and adjusts itself to provide the requisite function.

Typical requirements are the elimination of such gases as oxygen, carbon dioxide, and ethylene (the metabolic gas that ripens fresh foods). Conversely, the generation or retention of carbon dioxide to retard ripening might also be necessary and a moisture regulator might serve the same need in other products. Chemicals that either raise or lower the temperature in a film bag are also possible as is the incorporation of bacteriostatic additives to control spoilage organisms. These functions are added by combining different films or coatings, incorporating such chemicals as moisture or gas scavengers, or mechanical treatments such as microperforation, which will pass small molecules of selected size.

Already, some such techniques are being used abroad and being investigated in the United States. The market for permeable barrier films reached $72 million in 1993 and predicts 8 percent annual growth for the next five years due to rapidly expanding demand for controlled-atmosphere packaging of produce and other fresh products [13].

Metal Foils

Among flexible packaging materials, metal foil has one of the most outstanding positions: It is regarded as the perfect barrier to moisture and gases, far surpassing any single paper or plastic material. In appearance it has a luster and color that signals high quality, and it is widely used for packaging luxury items because of its glamorous appeal. It is fairly high in cost compared with other flexible materials, but if thinner gauges can be used, it can be worth the price.

History

Aluminum was first separated from its oxides as a pure metal early in the nineteenth century. The cost was so high, it was considered a precious metal. King Christian X of Denmark wore a crown made of aluminum and Napoleon III had a table service made from this material. For many years the world's greatest scientists tried to find a more economical method of extracting aluminum. It remained for the son of a Congregational minister, at the age of 22, to show the world how to do it. Charles Martin Hall had worked on this problem while attending Oberlin College in Ohio. Finally on 23 February 1886 in a woodshed behind the family home, he produced a small amount of pure aluminum with homemade crucibles and borrowed batteries. The pellets he refined are preserved in the Smithsonian Institution in Washington, D.C.

Aluminum, the third most common element on earth, is a hydrated oxide that is extracted from bauxite ore by the Hall-Heroult process in which bauxite is dissolved in molten cryolite (a salt, Na_3AlF_6) in a carbon-lined steel “pot.” A current, flowing through the mix from an anode to the cathode of the pot wall separates oxygen and alumina, the latter sinking to the bottom where it is siphoned off. Cast into ingots, the heated aluminum is rolled progressively into sheet and plate and, finally, foil.

By 1898, aluminum was commercial enough for Ball Brothers to use it in covers for its well-known home-canning jars. The first use of foil was in 1913 for wrapping Life Savers, candy bars, and chewing gum. Today aluminum foil still is used for candy wrappers and also can be found in bags for ground coffee, cigarette packs, retortable pouches, lidstock, aseptic pouches and cartons, and blister, strip, portion-control, and unit-dose packaging.

At the present time, about 234 million lb (106 million kg) of foil is produced in the United States for flexible packaging. Nearly all of it is aluminum foil although a small amount of tinfoil is still used for special products.

A good definition of foil is any rolled section of metal less than 0.006 in. thick (153.9 μm). Metal foil is available in gauges from 0.00017 to 0.0059 in. (4.4 to 151.3 μm) and in various tempers and surface finishes. The maximum available width in the United States is 72 in. (183 cm). Larger widths are available in Europe and Japan. Variation in thickness is held to a commercial tolerance of 10 percent. Flatness of foil, sometimes called shape, is difficult to control and becomes a greater problem as the gauge gets thinner. Additional information on aluminum for rigid packages is given in Chapter 10, Metal Containers.

Alloys

It is possible to make a 99.99 percent pure aluminum foil; such material is used for capacitors in the electronics industry. It is expensive and does not have the strength necessary for packaging applications. Most "commercial purity" aluminum for flexible packaging is around 99.5 percent pure, with about 0.4 percent iron and 0.1 percent silicon making up the balance. A higher iron content increases the bursting strength, which may be an advantage in strip packaging of tablets and capsules, but it reduces corrosion resistance. For pie plates and trays, 1.25 percent manganese and 0.2 percent copper often are added to provide greater stiffness.

In flexible packaging, alloys 1100, 1145, and 1235 are most commonly used. For pie plates and where heavier gauges are employed for stiffness, alloy 3003 is the most popular. The first digit of these alloy numbers indicates the principal added ingredient; thus the 2000 series contains copper, the 3000 series manganese, the 4000 series silicon, and the 5000 series magnesium (see Table 3.12).

Foil Temper

Hardness or softness is dependent upon the composition as well as the treatment of the aluminum foil. In the cold-rolling process, the metal becomes work-hardened and must be annealed for most purposes. Annealing is a heating process with slow cooling. Rolls of foil are heated to 650°F

TABLE 3.12. Aluminum Alloys Used in Packaging.

	Composition Percent						
Alloy	Al	Fe	Mg	Mn	Cu	Si	Cr
1100	99.0	0.45		0.05	0.2	0.3	
1145	99.45	0.45				0.1	
1235	99.35						
2024	93.4		1.5	0.6	4.5		
3003	98.5			1.25	0.25		

(343 C) for about 12 hours or until they reach the degree of softness desired. As a result of this heating, the rolling oils are burned off and the foil is said to be "dry." If half- or full-hard foil is to be used, it should be remembered that not all of the lubricant may be completely burned off and subsequent coating or printing may be more difficult.

Foil coming off the rolling mill is in an extra hard temper (H19) because of the strain hardening that occurs when it is reduced in thickness and must be annealed again before it can be used.

Heavy foils above 0.002 in. (51.3 m) are sometimes only partially softened to an intermediate temper (H25 or H27). For most applications, however, it is necessary to have good deadfolding properties and a dead soft temper, sometimes called 0-temper, is used. The tensile strength of aluminum foil is highest in the hardened state. When annealed, it loses more than half its strength. Alloy 1100, for example, has a tensile strength of 25 lb per in. (4.5 kg per cm) of width per mil (25.6 m) of thickness at the extra hard temper (H19). After annealing, this drops to about 12 lb per in. (2.1 kg per cm) of width.

Properties

Aluminum foil is used where the ultimate in protection from moisture or gas transmission is desired. When chosen for its barrier properties, foil is best put on the inside of a multi-ply structure, or buried in the plies, because it is very vulnerable to scratching and abrasion when exposed.

All foil also tends to have some pinholes from the mill-rolling process. Pinholes range in size from 1 10^{-7} to 3 10^{-5} $in.^2$ (6 10^{-7} to 2 10^{-4} cm^2), and the number found in gauges above 0.0007 in. (17.9 m) is considered to be negligible. A common thickness of foil in flexible packaging is 0.00035 in.

TABLE 3.13. Water-Vapor Transmission of Typical Foils.

Thickness (in.)	Grams Moisture per 100 in.^{2} per 24 h at 100 F, 100% RH
0.00035	0.30
0.0005	0.10
0.0007	0.03
0.001	0

(9 m). In 100 in.^{2} (645 cm^2) of such foil, the total area of all the pinholes will be about 4 10^{-5} in.^{2} (3 10^{-4} cm^2). See Table 3.13 for how this affects water-vapor transmission. Mill cleanliness is an important factor in limiting the number of pinholes.

Foil can crack if repeatedly flexed or creased enough and has poor tear strength. Lacquers, varnishes, and a lamination of tissue paper can offset these faults, but the papers, polymer coatings, and laminations that usually surround it are its primary protection. The least expensive material for bonding aluminum foil to paper is a sodium silicate solution, which is widely used for cigarette packages and soap wrappers. Other types of water-soluble and emulsion adhesives also can be used. For special applications, casein-latex formulations and resin emulsions may be required but are more expensive. A drying tunnel must be used before the material can be rolled up, and since the foil is a perfect barrier for moisture, the amount of dryness must be carefully controlled before it is trapped by coiling. If a foil-to-foil lamination is made, it will be necessary to use wax or other solvent-free adhesive because evaporation cannot take place through the foil.

Aluminum foil has a high resistance to most fats, petroleum greases, and organic solvents. Generally it resists acid products better than alkalies, although strong acids should be avoided. Weak food acids normally do not affect foil, except for acetic acids where a coating should be used to protect the material. Foil is virtually impervious to temperature extremes.

Aluminum foil in the softest temper will dead-fold with no springback. This facilitates forming it into any desired shape. Unfortunately, it also makes it wrinkle easily, so great care must be used in handling to avoid spoiling its smooth surface. Since aluminum is very ductile, it can be stretched quite a bit if the proper tools are used. Pouches are sometimes made this way for bulky items by forming pockets to conform to the shape of the product. However, aluminum has rather poor tensile strength and tears quite easily.

TABLE 3.14. Foil Surface Finish Designations

B2S	Bright two sides
Embossed	Pattern is impressed by engraved roll or plate
EB2S	Extra bright two sides
M1S	Matte one side
M2S	Matte two sides
MF	Mill finish

Decoration

Foil is generally smooth and shiny and can be tinted to produce almost any metallic color. Attractive matte, brushed, and embossed textures also are available. Coded designations identify different foil surfaces such as bright, extra bright and matte (see Table 3.14).

Aluminum foil is usually printed by the flexographic process, although for long runs and high-quality color work, gravure printing is sometimes used. To improve ink adhesion, a primer may be required.

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Chapter 4— Coating and Lamination of Flexible Materials

Introduction

The fastest growing packaging forms in the world are now, and will be for some time to come, made from flexible materials.

So versatile are papers, films, and foils that new types and combinations of types are continuously being developed. The choices are further complicated by the many ways in which such combinations of materials, adhesives, and coatings can be made to alter and enhance the properties of the basic materials. It is a truism that no single material can provide all of the requirements for all products. Hence, the continuing effort to improve strength, barrier properties to moisture and oxygen, flavor retention, odor resistance, heat-sealability, scuff protection, and machinability (by reducing surface friction and blocking). How these improvements are achieved is the subject of this chapter.

The easiest method for improving the characteristics of paper, film, or foil is the addition of a coating. Since it generally is thinner than the lightest film that could be used for the same purpose, it usually is less costly than a lamination. Major applications for coatings generally break down into overcoats that protect surface printing, heat-seal and barrier coatings, and laminating adhesives. Other additives provide waterproofing, dying, and preservative functions. Many coatings play multiple roles.

The market for press-applied surface coatings and waxes totaled 818 million lb (368 million kg) in 1994 and was valued at $557 million [1]. The extrusion coating market is believed to be even bigger.

Cellophane, the first transparent flexible packaging material, could never have reached the dominant place it occupied in packaging for more than 40 years if it were not for the variety of coatings that were developed to increase its strength, barrier properties, and heat-sealability. Coatings also have been applied to many other papers, foils, and plastic films to open up whole new fields of pouch and bag packaging and to enable significant source reduction in the amount of material required to protect and transport both dry and liquid products.

Coatings also are used on paperboard and corrugated and discussed in Chapters 2, 6, 7, and 14.

Coupled with surface treatments is the rapidly growing technology of combining several materials and coatings to utilize the best features of each, and in this way achieve results not possible with any one material alone. The term "structured films" is applied to such combinations, which are formed with the aid of coating, lamination, and coextrusion. Such materials are found in an ever growing number of packaging applications (Table 4.1).

Laminations have been in commercial use for more than 40 years, but it is only since the 1980s that the great multiplicity of combinations has become available. With about 20 different films to work with and a dozen or more kinds of paper, plus metal foils and a few woven and nonwoven fabrics, the number of possible combinations is virtually limitless. A few common structures and applications are shown in Table 4.2.

So complex is this technology that selection of the most costefficient/functional material for a specific application at any given moment in packaging history requires all of the knowledge and skill of a packaging professional.

In barrier constructions, one important task is to calculate the oxygen and water-vapor transmission rates (OTR and WVTR). The following formula can be used to get a close evaluation of either OTR or WVTR of a multilayer structure for initial purposes [see Chapter 3, Table 3.5 to find transmission rate (TR) values]:

$$TR = \frac{1}{\frac{\text{Layer 1 (mils)}}{\text{Layer 1 TR}} + \frac{\text{Layer 2 (mils)}}{\text{Layer 2 TR}} \frac{\text{Layer 3 (mils)}}{\text{Layer 3 TR}}}$$

TABLE 4.1. Packaging Uses of Coated Flexible Materials.

Laminations
Multiwall bags
Single-wall bags
Pouches
Overwraps
Bag-in-box structures

TABLE 4.2. Common Multilayer Flexible Structures and Applications.

Multilayer Structure	Application
Two-side PVDC-coated Cellophane/PE/Foil/PE	Nut, dehydrated soup mixes dry chemicals, pharmaceutical powders
Glassine/LDPE/Foil/LDPE	Tobacco
Paper/Foil	Wrappers for chewing gum, cigarettes margarine/butter soap, carton overwrap, carton liner for sugar-coated cereal
Paper/LDPE/Foil/LDPE	Dry soup, drink mix
LDPE/LDPE	Rice
Nylon/PVDC/PE	Meat, cheese
Metallized Nylon/LDPE	Coffee
PVDC-coated Nylon/Ionomer	Lunch meat and hot dogs
Polyester/PVDC/PE	Meat, cheese
PVDC-coated PET/LDPE	Processed meat
PVDC/PVC	Blister packaging
BOPP/LDPE	Candies, cookies
BOPP/PVDC-coated BOPP	Candy bar wraps

Here's an example of how the formula would work for a three-layer structure using 0.5 mil of PVDC where Layer 1 is 1.5 mil with an OTR of 500, Layer 2 is 0.5-mil with an OTR of 0.05, and Layer 3 is 2.0 mil with an OTR of 1,200.

$$\frac{1}{\frac{1.5}{500}+\frac{0.5}{0.05}+\frac{2.0}{1{,}200}} = 0.10 \text{ OTR}$$

See Table 3.5, Chapter 3, Films and Foils for the OTR and WVTR rates for some common films used in coatings and laminations.

History

Interest in coatings began almost a century ago. The earliest packages of Kellogg's Corn Flakes—a folding carton with a bag liner of plain white paper, for example—appeared on the market in 1906. The instructions on the package were: “To restore crispness, heat in a pan in a moderate oven.”

To improve this package, experimental work was done with wax as a coating material and, in 1912, a waxed carton liner known as the Waxtite wrap was added. This helped preserve product crispness and provided a real advantage over competitive brands of dry cereals, which were beginning to flood the market at that time.

In 1938 waxed glassine was introduced. Made with waxes having a higher melting point, it provided better moisture protection and reduced the tendency of such materials to block (stick together) in hot weather. Although wax has excellent barrier properties against moisture, it is a rather poor grease and odor barrier and it makes a relatively weak seal.

With the introduction of polyethylene (PE) in the late 1940s and the development of microcrystalline waxes by the oil refineries shortly thereafter, a blending of these coating materials helped extend their usefulness.

Varnishes had been used to some extent as greaseproof coatings on paper, but the introduction in 1948 of a polyvinylidene chloride (PVDC) resin, a copolymer of vinyl chloride and vinylidene chloride often called Saran [2], was a major breakthrough in barrier coatings.

Extrusion coating with low-density polyethylene (LDPE) developed in the late 1940s and early 1950s and provided flexible-material converters with a particularly useful range of heat-seal coatings.

Cellophane, which made its mark first with a nitrocellulose heat-seal coating, was extrusion-coated with LDPE in 1953. The following year, LDPE was applied to aluminum foil, vastly broadening its use for very high barrier applications. Foil is expensive, however. Moreover, in laminations it can limit the recyclability of film and cellulosic substrates. As a result, packagers have increasingly looked to metallizing, a process which deposits an extremely thin layer of aluminum on film or paper for both decorative and barrier purposes.

Barrier plastics, such as the veteran PVDC and, more recently in the 1980s, ethylene vinyl alcohol copolymer (EVOH), also achieve high barriers in very thin layers and have replaced foil to some extent. Other materials have been added to the list, and the number is constantly increasing.

Coating Techniques

The method of applying a coating is determined somewhat by its viscosity. For example, air knifes, blade, and bar coaters will not handle very viscous materials, but perform well with emulsions, clays, and other pigments.

An air knife consists of a slotted jet of high-velocity air that virtually "peels" excess coating from a traveling web, leaving a very uniform thickness (see Figure 4.1). Normally used with water-base materials, it tends to be incompatible with coatings containing volatile solvents.

Gravure-roll coating also is used primarily for lightweight applications, since excess coating is scraped away by a doctor blade, leaving only the material in the engraved patterns on the roll.

Cast coating deposits a coating on the surface of a polished roller for transfer to a packaging material (see Figure 4.2). A primary use of this technique is for deposition of an extra clay coating to paperboard to create the smoothest (and most expensive) printing surface. Casting as a final operation protects a delicate coating from being damaged by heat treatments required in previous coating steps.

Products of intermediate densities generally are applied via a rollercoating method (see Figure 4.3). The roller coater, in its various forms, is widely used for packaging. Rollers can be run in the same direction as the web or in reverse to change coating thicknesses and characteristics. Dual or

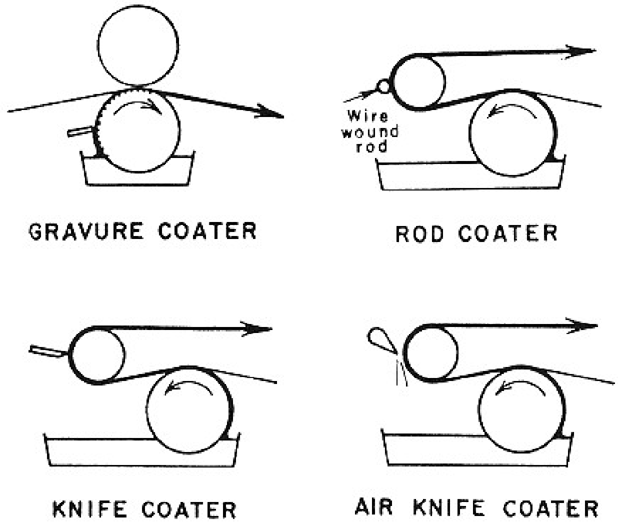

Figure 4.1.
Lighter viscosity coatings can be accurately metered with gravure, rod or mechanical and air knives.

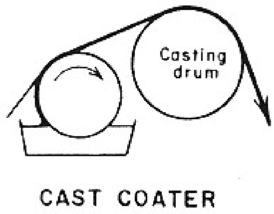

Figure 4.2.
The casting method transfers thicker coatings from a polished roller to the web.

triple rollers can be coupled to squeeze coating material into thick or thin layers.

Calendering squeezes the coating through two rolls to form a very thin sheet that is then transferred to the substrate. This process sometimes is used to create monolithic films, notably polyvinyl chloride (PVC) (see Chapter 3, Films and Foils).

The most economical way to combine thermoplastics such as PE with other flexible materials in large quantities is by extrusion coating. The extrusion process forces a stream of molten coating material through an adjustable, long slit in a die and onto a web of paper or other substrate moving beneath it. As the materials contact, the web is chilled to set the molten coating (see Figure 4.4).

A variant, the curtain coater, allows a heavier stream of coating material to pass by gravity or modest pressure through a slotted orifice onto the surface of a moving substrate (see Figure 4.4). It is useful for both very heavy cold coatings and hot-melts, but is not as controllable in thickness as extrusion coating.

Both extrusion and curtain coating work at relatively high temperatures. The objective is to promote rapid oxidation of the bonding surface, which fosters adhesion. Unfortunately, oxidation can lead to the generation of odors. If the material is to be used for food products, the process must be controlled carefully to minimize odors.

Oxidation of the surface coating also can interfere with heat sealing when the lamination is converted into packages. But sealing problems should not be solely attributed to oxidation without checking other causes as well. It is equally likely that heat-seal troubles are caused by slip agents or other additives, which are brought to the surface of the film by the heat. Since the oxidation and additives can vary from one batch to another, it may be necessary to adjust sealing temperatures and dwell times for each lot of material passing through a fabricating or packaging machine.

An extrusion coating is generally softer than a lamination of the same material. If both the substrate and the coating are soft, the combination can cause machining problems. If stiffness is necessary to push the material through a bag machine, for example, it may be necessary to use an adhesive lamination of the materials.

Extrusion-coated material can have a tendency to curl, too, if the substrate is porous and can absorb moisture. A light barrier coating or lacquer on the

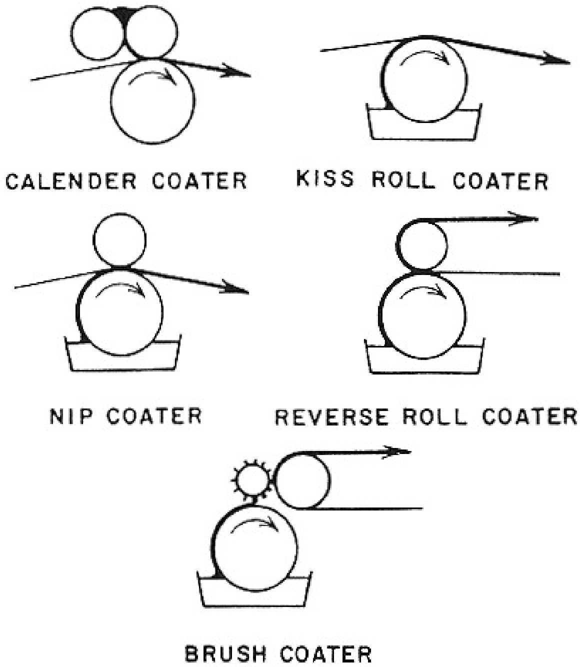

Figure 4.3.
For medium viscosity coatings, roller methods are used.

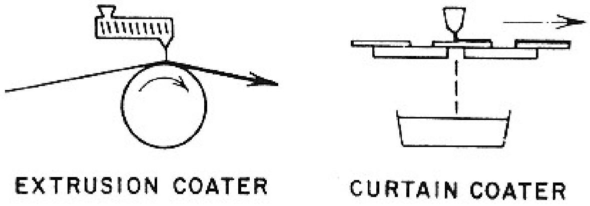

Figure 4.4.
Heavier coatings like polyethylene work best with extrusion or curtain coaters. Extrusion offers better thickness control.

substrate's off side can help prevent such curl, which will create chaos in a labeling operation, for example.

Then, there are substrates that have poor adherence to coatings. Preapplication of various primer coatings can solve this problem, especially with foils that do not have a surface with "bite" to which the coating can adhere. "Nonpolar" plastics such as the PEs, which do not bond readily, may use various primers or flame or electrostatic surface treatments (see Chapter 3, Films and Foils and Chapter 8, Plastics).

Coating Materials

Books have been written on the vast number of coatings available for packaging and there is not enough room here to discuss each one in depth. However, we will describe the most important types and how they perform their functions, which will reveal the basic principles of coating technology. Additional information is covered in Chapter 3, Films and Foils.

Surface Coatings

Surface coatings are used to provide scuff-resistance, gloss, and slip (reduced friction). Formulations include nitro-and ethylcelluloses, polyamides, acrylics, and waxes—either alone or in mixtures. Where high heat-sealing temperatures are used to form and close pouch and bag structures, such thermoset coatings as polyesters and urethanes are employed to protect printed materials. They chemically combine with film surfaces to create a bond that is not affected by high temperatures.

Surface coatings can be solvent-or water-based and generally are applied on the printing press, although off-press coating is used when all press stations are occupied by inks.

In recent years, there has been a major shift to water-based coatings to meet clean-air requirements of the Environmental Protection Agency (EPA), Washington, D.C. Solvent-based coatings require collection and destruction of evaporated solvents in expensive ovens, a costly operation.

Reactive coatings chemically combine with the substrate either by the application of heat, irradiation, or ultraviolet light. Another group of long-used surface coatings, clay, calcium carbonate, and titanium dioxide, typically are used to produce smooth, white, highly printable surfaces.

Varnishes and Lacquers

Numerous resins are used singly or in combination as varnish coatings for flexible webs. They may contain modifiers and be preceded by a coating of an adhesion promoter. Some varnishes may be alcohol-based or, if they contain wax, may be thinned with naphtha and are called "spirit varnishes." Others, known as "press varnishes," are used without solvents and dry by oxidation rather than by evaporation. There are now water-based varnishes as well.

All types are used on-press to add a protective coating, which prevents smearing and scuffing of the printed ink and/or provides a glossy finish. They are the least expensive materials for the purpose and are easy to apply by gravure and flexographic printing techniques. In the past, most gravure coaters were used only with solvent-based coatings. However, they now have been adapted to apply the more popular water-based coatings as well.

The effectiveness of a coating is dependent to some degree on the amount that is used. A coating of a 0.5 lb of solids per 1,000 ft^2 (227 g per 92.9 m^2) will obviously not do as good a job as 2 lb (907 g). If it is intended only for appearance, then the lighter coat may be sufficient, but if protection from scuffing is required, then a heavier application may be necessary. If varnishes are printed only in certain areas, they are known as "spot varnishes." Varnishes also can be "dropped out" (omitted) where necessary to keep white areas from yellowing with time, facilitate gluing, or permit stamping of price marks or code numbers on the package.

Lacquers made from vinyl-type resins and more volatile solvents than varnishes usually offer a better grade of coating, but tend to cost a bit more too. Even more sophisticated are epoxy-type coatings made from thermosetting resins. They require special ovens for curing, but provide a hard, lustrous finish that cannot be obtained any other way.

Heat-Seal

Virtually all of the materials mentioned above also can be used as heat sealants. Selection is based on the role or roles each is intended to play. PVDC can be used as a sealant, for example, but the type of vinylidene chloride copolymer used as a sealant is not the best one for barrier properties.

Moderate sealants sometimes can be improved by adding ethylene vinyl acetate (EVA), which boosts both hot tack and strength. For overall performance, it is hard to beat the LDPE family. With its range in density and melt index, it is the foremost heat-seal agent in flexible packaging.

Heat-seal coatings generally are applied over the entire surface of a flexible material, but also can be applied in stripes to both sides of a material where only overlap seals are required. Pattern coating also is possible for special flexible constructions. An example is cohesive or cold-seal coatings. These latex-based adhesives adhere only to themselves and not to other parts of the flexible-packaging structure. They generally are applied in stripes to one side of the packaging material (two-side coating would seal the material to itself in the roll) and require a coated face to coated face fin-type seal to form a pouch package. Cohesive coatings are used mainly for such temperature-sensitive products as confections where heat-sealing would cause product damage.

Waxes

The oldest and still very widely used coating material is wax. There are two methods for applying wax to paper: “dry waxing” and “wet waxing.” In the dry waxing process, the paper travels over hot rollers after being coated, so that the wax soaks into or saturates the paper and does not stay on the surface. In wet waxing, the wax is chilled quickly by cold rollers or by being run through a water bath, so that it does not penetrate but stays on the surface, producing a glossy appearance (see Figure 4.5).

Both paraffin and microcrystalline waxes are used in coating papers and corrugated and as adhesives to laminate papers and paper-and-foil combinations and other substrates. Paraffin waxes offer excellent barriers to moisture and oxygen and resistance to greases and oils. But their relative low melting points (120 to 160 F, 49 to 71 C), can cause blocking (adhesion) in packages subjected to summer transport where temperatures as high as 135 F (57 C) or more have been measured inside parked trailer trucks. Therefore, they are usually modified by the addition of microcrystalline waxes, PE, ethylene copolymers, and other resins. Various hot-melt adhesives also are blended with these other materials to provide greater adhesion.

Microcrystalline waxes do not have quite as good a barrier as paraffin, but

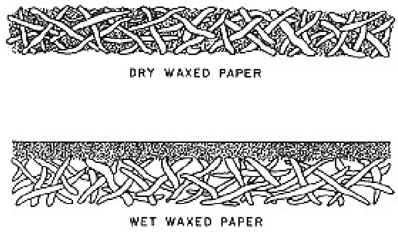

Figure 4.5.
The two methods of putting wax on paper are illustrated schematically. In dry waxing the paper is heated after it is coated, and the wax soaks into the paper. In wet waxing the wax is chilled before it has a chance to penetrate the paper.

generally have higher melting points, ranging from 140 to 195 F (60 to 91 C). Waxes ranging from 160 to 195 F (71 to 91 C) are used in coatings, those ranging from 140 to 175 F (60 to 79 C) in laminating adhesives. Added in small quantities to paraffins, the microcrystallines improve heat-seal strength and scuff resistance without reducing barrier properties. Added to adhesives, they add flexibility, toughness, and adhesion.

It should be noted, though, that additives can affect gloss and application at too high a temperature can create oxidation by-products that impart a bad odor to the material. Addition of antioxidants can aid in the control of this problem.

Polyethylene

By far the most common coating materials are the PEs, a family of compounds with a broad density range of 0.890 to 0.960 g per cm^3. Those used for coating include LDPE, very-low-density polyethylene (VLDPE), medium-density polyethylene (MDPE) and linear-low-density polyethylene (LLDPE) as well as numerous ethylene copolymers, most of which have been mentioned above. The range of olefin-type materials is so broad that a wide variety of heat-seal and barrier coatings can be formulated from these compounds and their combination with other materials.

The heat-seal range of PEs and their puncture resistance, low-temperature resistance, and flexibility improve with lower density. Heat-seal temperatures increase with density and with lower melt indexes. Molecular-weight distribution also has an effect. A narrow distribution produces a more limited range in heat-sealing (see Chapter 8, Plastics).

MDPE is used in multilayer structures when better barriers and resistance to higher temperatures are required. LLDPE is favored in such structures, too, and is replacing MDPE in some of the more severe applications. In recent times, oriented high-density polyethylene (OHDPE) has been coated for single and duplex heat-sealable structures where great tear resistance and stiffness are an asset. OHDPE also has been laminated to other materials such as polypropylene (PP) for food pouches and paper for candy twist wraps.

Plastomers

Polyolefin plastomers (POPs) composed of high-performance ethyleneoctene copolymers are now used widely as sealants in multilayer flexible packaging structures. High hot-tack and heat-seal strength creates seals with approximately 11 lb/in. (2 kg/cm) strength at a seal-bar temperature of about 220 F (104 C). This is particularly useful with polyethylene terephthalate (PET) and PP structures where improved heat-sealing performance is critical. Plastomers also have low haze and, therefore, improved optics for such film applications. These sealants can be extruded as films or coatings and are competitively priced at about $0.90 per lb.

Other widely used sealants include EVA, ultra-low-density polyethylene (ULDPE), and ionomers. In addition to sealant and tie-layer applications in multilayer films, these materials also are used as films for produce bags and some form-fill-seal pouches.

Polyvinylidene Chloride

This high-barrier coating material evolved from films and coatings developed in the 1930s and used during World War II. The homopolymer has a melting point that is only slightly below that of its decomposition temperature, which was troublesome in the beginning.

However, by the 1970s, polymerization with such comonomers as vinylidene chloride, methyl methacrylate, and acrylonitrile had improved its properties and enabled it to be broadly used as an aqueous latex dispersion, solvent lacquer, or melt extrusion. A relatively recent copolymer using methyl acrylate has almost twice the gas barrier of PVDC containing the more common vinyl-chloride comonomer.

To date, this family of resins has been applied on or between almost every multilayer paper and film structure requiring a barrier to moisture, gases, odors, greases, and oils (see Table 4.2). It is even heat sealable.

For papers, a water-based latice application is favored for candy and soap wrappers and cereal-box liners, to name but a few applications. Films can be coated with either latices or solution coatings and surround a broad variety of food products such as meats and cheeses. Cellophane is coated with the solvent-based type that protects the film from moisture absorption. Dry cellophane has a good barrier to gases and, thus protected, is still used in many multilayer materials. PVDC is often applied to a substrate in several coatings to increase its barrier and sealability.

Ethylene Vinyl Alcohol

EVOH copolymer is the second most popular highest-barrier plastic coating used in packaging. It provides a very high barrier to gases, oils, and organic solvents (see Table 4.3). EVOH's problem is that it is water soluble and its barrier to gases decreases a hundredfold with a 0 to 100 percent increase in relative humidity (RH). For this reason, EVOH is used in a sandwich of films that provide a good barrier to moisture, such as PP, which is also relatively economical. Nylon and EVOH is another useful combination. In such applications, adhesives often are required to create a satisfactory bond between EVOH and other plastics.

Amorphous Nylon

This condensation reaction between metaxylylene and adipic acid does not have extraordinary barrier properties alone (see Table 4.3), but it does have thermal stability to 194 F (90 C). As a result, it has won uses in multilayer films with biaxially oriented polyethylene terephthalate (OPET) for hot-filling applications, which are beyond the capability of EVOH. It is applied by extrusion.

Metallization

The history of metallization starts in the 1930s when Christmas tinsel was first made from metallized film instead of thicker foil. However, it was not until the mid-1970s that the process was adapted for coating packaging papers and films.

Double-digit growth occurred in the late 1980s and 1990s as the cost and environmental considerations of using foil laminates made packagers seek a more cost-effective/functional alternative to improving both package appearance and barrier properties. Although the rate has slowed, metallizing is expected to continue to grow at 5 percent per year until the turn of the century [3]. Annual demand for metallized film and paper for packaging was estimated at 117 million lb in 1995. Of this 60 percent is metallized OPP and PET and 30 percent is metallized paper and paperboard [4].

Creating more marketing impact for alcoholic-beverage labels kicked off

TABLE 4.3. Barrier Properties and Costs of Some Common Composite Materials.

Multilayer Structure	0_2 Trans.	WVTR	Cost $\$$/1,000 in.^{2}
48-ga. OPET/adh/2-mil LLDPE	0.5	6.0	0.26
50-ga. OPET-PVDC/adh/2-mil LLDPE	0.3	0.5	0.30
48-ga. OPET-EVOH/adh/LLDPE	0.3	0.1	0.34
Paper/LDPE/0.000285-in. foil/LDPE	0.01	0.01	0.14
Nylon-LLDPE/sealant	1.0	0.8	0.11
OPET/PVDC/PE sealant	0.1	0.8	0.14
OPP/PVDC-OPP	1.0	0.01	0.16
OPP/adh/met-OPP/cold sealant	2.0	0.02	0.28
OPP/OPP sealable	100	0.3	0.11
OPP/LDPE/met-OPP	2.0	0.01	0.18
OPP/LDPE/met-OPET/LDPE/ionomer	0.02	0.05	0.28
paper/met-OPET/LDPE	0.03	0.01	0.20
HDPE-coex-sealant	100	0.1	0.10

cc/100 in.^{2}/24 h/73 F/0% RH.

g/100 in.^{2}/24 h/100 F/40% RH.

the trend. Not only does the decorative effect equal that of foil, but the resultant labels exhibit less curl, simplifying the labeling operation.

This huge market was followed by growing snack and confectionery markets pushing scores of new products that not only require more dazzling packaging, but better barrier properties to sustain fragile ingredients over longer shelf lives. Another example is the use of metallized film and paper structures for bags of vacuum-packed coffee.

Metallized and reverse-printed films also have been laminated to paper and paperboard for product applications where the package is exposed to wet or high-moisture environments. In unit-dose pharmaceuticals there is some use of metallized films to replace foil backing sheets, and patternmetallized “susceptor sheets” that focus microwave energy to heat specific product areas in microwaveable foods is a potentially large application. Another area showing promise is embossing metallized substrates with holographic images to generate on-shelf excitement and/or deter counterfeiting.

At much lower cost, metallized papers and films create the appearance of foil, widely perceived by consumers to indicate protective quality in a packaged product. Improvements in metallizing machinery and technique and smoother, better-prepared film and paper substrates have resulted in substantial improvement of barriers to gas, moisture, and light transmission. The major packaging films metallized today are PET, PP, PVC, nylon, and PE. Even more popular is metallized paper, probably because it can offer savings of 5 to 16 percent compared to foil/paper laminations. Today, some metallizers can handle webs as wide as 125 in. (3,175 mm).

Deposition of a thin coating of metal is a high-vacuum process. The substrate, either paper or film, is unrolled through a high-vacuum environment where for packaging applications vaporized aluminum from continuously fed pots or boats condenses on the web to form the thin coating (see Figure 4.6). With a thickness of 0.28 to 0.56 10^{-6} in. (0.007 to 0.014 m), the coating can be more easily measured by optical density (OD), the proportion of available light passing through it. Ratings are usually in the range of 1.2 to 2.3 percent.

In this process, vacuum is critical to reach the high vacuum level of about 0.9 in. (2.3 cm) mercury that allows aluminum to melt at an economical temperature of about 3,100 F (1,700 C). Equipment is differentiated according to heating method—resistance, induction or electron beam—and single and dual vacuum chambers are used. Resistance heating is most common today and has superseded the once popular induction method. However, e-beam is

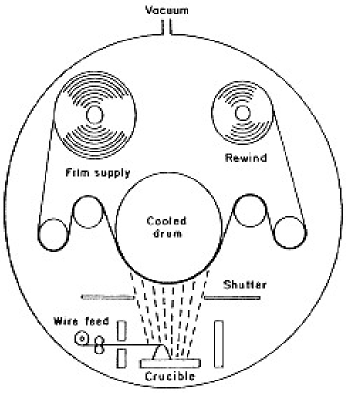

Figure 4.6.
Film and paper webs are most commonly metallized in a vacuum chamber where an aluminum wire is fed into a crucible, melted, and vaporized. Once proper temperatures are reached, a shutter opens an aperture below the moving web releasing the vaporized metal, which condenses on the cooler film.

capturing attention because although more expensive, it is considered to be simpler and offers high deposition rates as well as flexible changeover.

Film is smoother and comparatively easy to metallize and single-chamber metallizers are just about limited to this application, today. Paper is more difficult because of its moisture content, which vaporizes and contaminates the vacuum. Clay-coated stock typically is used to improve the coating surface and the reflective values of the metallized surface. To further smooth the surface and retard outgassing, a lacquer coating is applied before metallizing. Post-metallizing, a top lacquer coating prevents the aluminum from oxidizing and provides a suitable surface for printing. The web also is likely to need humidification to restore the paper's moisture content and improve its resistance to curling.

An increasingly popular transfer process is also feasible. Here, the metallic layer is first deposited on a smooth film, such as PP, then transferred to a paper coated with adhesive. Benefits are use of a lower grade of paper while still achieving a high-gloss metallic finish. A good dual-chamber metallizing system can tolerate papers with about 5 percent moisture content.

Silica

One of the newest barrier coatings in packaging—and one that is intriguing to flexible packagers because of its unequalled barrier properties in very thin coatings—is silicon oxide (SiO_x). It was pioneered in the late 1980s in Japan, where it currently is used commercially not only on films, but also on plastic bottles and sheet-formed trays. Silicon-coated films are used in some packaging now in Europe and there are a handful of commercial applications in the United States, including a PE/silica/PE/paperboard/PE laminate for extended-shelf-life juice and an adhesivelaminated silica-coated PET/silica-coated PET/LLDPE film for medical device packaging.

Similar to metallizing, silica coatings can be deposited on films by evaporation, sputtering, and plasma treatments.

The evaporation process takes place in a high-vacuum chamber where mono- and dioxide silicas are heated in a crucible, vaporize, and condense on a film web traveling on a chilled drum, which prevents the film from melting in the elevated temperature (Figure 4.7) [5]. Although speeds have improved, energy requirements are high and chambers must be cleaned frequently because the glass coats everything it contacts. The resulting film has a yellowish tint due to the coating.

Sputtering is similar in action, but involves a negatively charged cathode of silica. A mixture of argon and oxygen gases are flowed into the vacuum

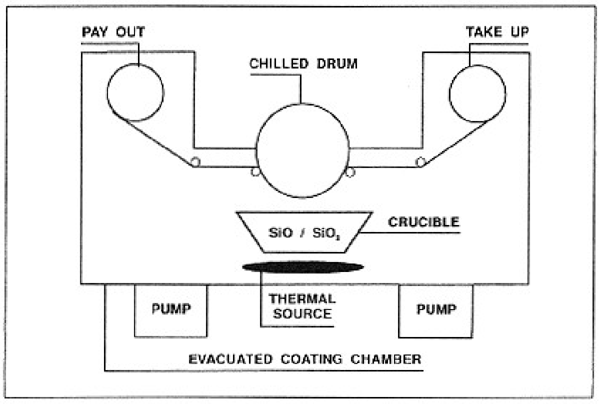

Figure 4.7.
In a process similar to metallizing, silica coatings are applied by evaporation in a high-vacuum chamber where mono-and dioxide silicas are heated in a crucible, vaporize, and condense on a film web traveling on a chilled drum.
(Source: PC Materials, Mt. Bethel, Pennsylvania.)

chamber, become positively ionized and the argon ions bombard the cathode to dislodge silicon atoms that deposit on the chilled film web (Figure 4.8) [6]. High power consumption, low deposition rate, and slow speeds make this process prohibitive for packaging at this time.

Plasma deposition, a low-temperature process developed in the United States, reportedly produces a more uniform coating and improves resistance to physical abuse because it produces a chemical rather than physical bond. In the coating chamber, electromagnetic or microwave energy creates an energized collection of electrons, ions, and reactive molecules from a mixture of gases including oxygen, helium, or nitrogen and a silicon-based monomer such as tetramethylsiloxane or hexamethyldisiloxane. The plasma breaks the silicon monomer apart, whereupon the oxygen combines with the methyl groups to form carbon dioxide, carbon monoxide, and moisture vapor and with the silicon to form SiO_2. Multiple coating zones in some chambers increase coating speeds (Figure 4.9) [7].

Smoothness of the film substrate naturally has a bearing on uniformity and, therefore, the barrier properties of the coated film. On PET and PP films, the plasma process has achieved very low oxygen and moisture trans-

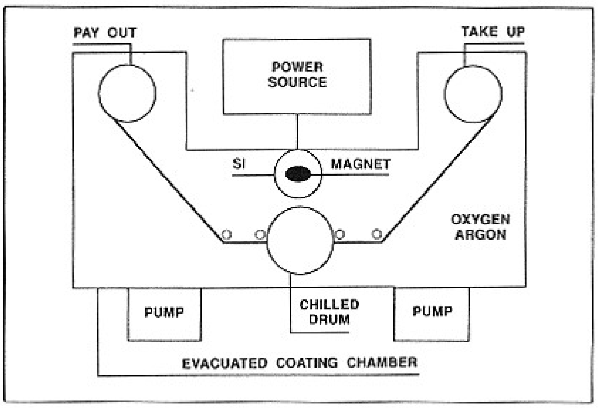

Figure 4.8.
Akin to evaporation, sputtering applies a silica coating via a negatively charged cathode of silica. A mixture of argon and oxygen gases flowed into the vacuum chamber becomes positively ionized, and the argon ions bombard the cathode to dislodge silicon atoms, which deposit on the chilled film web.
(Source: PC Materials, Mt. Bethel, Pennsylvania.)

mission values with optically clear coatings as thin as 300 to 400 Å (1.17 10^{-6} and 1.56 10^{-6} in., 0.03 and 0.04 m). To protect this ultra-thin layer, silica coatings generally are sandwiched between softer and more flexible films. While silica coating has been rather expensive in its developmental stages, recent advances in speed and efficiency have brought costs down to \$0.03 per 1,000 in.^{2} (6,452 cm^2), which can price a 48-ga. (12.3- m) silica-coated PET film at about \$0.14 per 1,000 in.^{2} (6,452 cm^2).

Water Soluble/Edible

Used for centuries as adhesives, edible proteins are now receiving heightened attention due to perceived environmental advantages. Derived from renewable resources, such "natural polymers" can be disposed of through composting or sometimes recycled as animal feed. Corn zein, for example, has potential as a heat-seal coating for paper, according to a study done at Clemson University, Clemson, South Carolina [8].

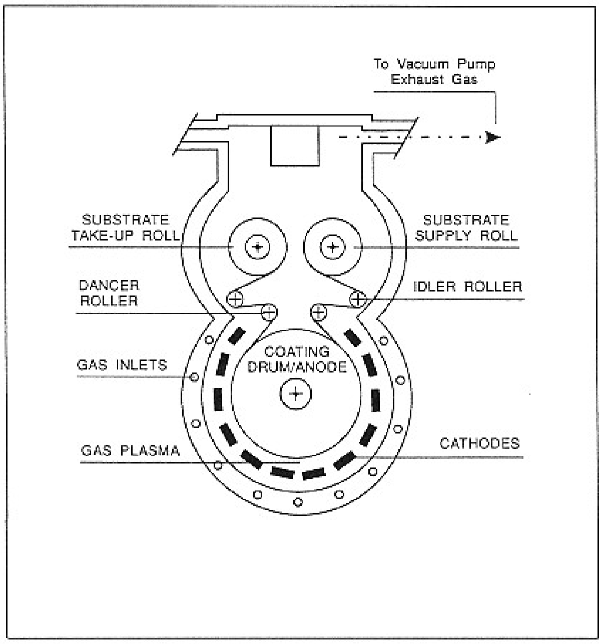

Figure 4.9.
Unlike the other silica coating processes, plasma deposition is a low temperature process. In the coating chamber, electromagnetic or microwave energy creates an energized collection of electrons, ions, and reactive molecules from a mixture of gases including oxygen, helium, or nitrogen and a silicon-based monomer such as tetramethylsiloxane or hexamethyldisiloxane. The plasma breaks the silicon monomer apart, whereupon the oxygen combines with the methyl groups to form carbon dioxide, carbon monoxide, and moisture vapor and with the silicon to form SiO_2.
(Source: PC Materials, Mt. Bethel, Pennsylvania.)

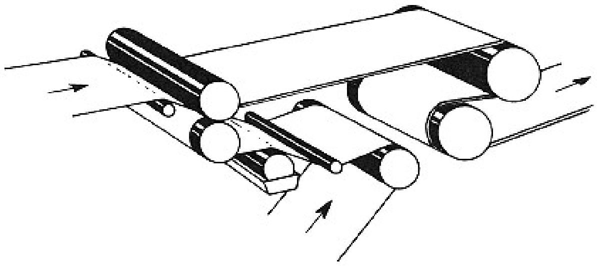

Figure 4.10.
In one type of laminating, two or more webs are joined with adhesive. In the figure, one web comes up from the bottom and is carried over an adhesive roller to the left. A second web coming in at top left meets the adhesive-coated web in the nip of the two rolls, which are one above the other on the left. The combined layers pass around the snub rolls to the right and are carried to the next operation.

Laminations

The fundamental action involved in lamination of flexible materials is the bringing together and bonding of two or more webs by means of some adhesive agent to create a single web (see Figure 4.10). The basic reason for performing this function is to create a structure that contains all required packaging properties, which, in many cases, have to be supplied by more than one material (see Figure 4.11).

The boundaries between conventional methods of laminating are definitely becoming blurred. Divided between adhesive and extrusion processes, we will define five basic methods: (1) water-based adhesives,

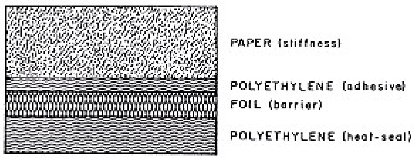

Figure 4.11.
A cross section of a typical lamination is shown greatly enlarged. As indicated, each layer has a specific purpose. The paper layer is on the outside of the package in this case and can be printed. The inside surfaces are intended to be sealed to each other with heat.

(2) solvent-based adhesives, (3) thermoplastics, (4) hot-melt coatings, and (5) coextrusion. Sometimes combinations are used.

Water-Based Adhesives

Water-based adhesives form one type of "wet-bonding" process that is increasingly popular for environmental reasons. It requires at least one side of the lamination to be permeable, allowing escape of the adhesive's water content. A long-time example is the combination of aluminum foil with a thin tissue paper, generally using casein or sodium-silicate adhesives. However, this process also is limited in scope.

Solvent-Based Adhesives

Solvent-based adhesives are used in another wet-bonding process, which has broader application. However, it also is becoming increasingly expensive because the resulting vapors must be captured to meet environmental regulations. Here too, one substrate must be permeable to solvent vapors. The exception is a so-called "dry-bonding" process that coats one substrate with a solvent adhesive, which is dried to remove the solvent and then combined with a second substrate in a thermal/pressure laminator.

Thermoplastic Materials

Thermoplastic materials or materials that have been previously coated with a thermoplastic can be laminated very simply with heat and pressure. This inexpensive technique is much used, because many large converters specialize in producing certain basic multilayer substrates like PE-coated paper that are then further structured by other film laminators.

Hot-Melt

Hot-melt laminating differs from the above mainly by operating at lower temperatures with mixtures such as the waxes, which create lower cost materials of limited complexity.

Coextrusion

Coextrusion is only a 30-year-old process, first performed in 1964, in which all of the film-forming constituents of a composite material are simultaneously flat-die extruded or blown and combined in the molten state (see Figure 4.12). A large proportion of the primary substrates are based on PP

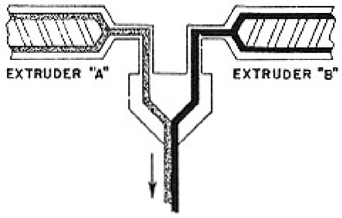

Figure 4.12.
The coextrusion process makes a composite film from two or more materials by forcing melted polymers through a slit die.

and PE, but nylon, PVC, PVDC, EVOH, EVA, and other thermoplastics also are used, as well as specialized adhesives that wed disparate surfaces together.

Since all of the plastics start out as fluids and cool together, coextrusion eliminates the multiple steps required by some of the other techniques. In large quantities, coextrusion can be less expensive than other methods. However, scrap losses during setup and changeover make the process less attractive in small quantities. Here again, large converters tend to make fundamental composites that can be customized by smaller converters. For details and examples of how these processes are used, see Chapter 3, Films and Foils.

Selecting an Adhesive

In laminating, adhesives are used to mechanically bond such materials as paper into which the adhesive can penetrate, chemically bond two or more materials by reaction between the materials and the adhesive, or create a surface attraction by setting up electrostatic forces, which generate surface energy. The complete "wetting" of material bonding surfaces to create flawless adhesive laminations is particularly important in the union of such nonpolar materials as the polyolefins.

The amount of adhesive required varies with the type used and the nature and application of the lamination. As an adhesive, for example, PE can range in application from about 1 to 5 lb (0.5 to 2.3 kg) per ream (3,000 ft^2, 278.7 m^2) for consumer-sized bags and pouches to 30 lb (13.6 kg) per ream (3,000 ft^2, 278.7 m^2) for large industrial bags. Very light applications of special wax or sizing adhesives are used for heat-transfer decoration of containers (see Chapter 12, Labeling and Decorating).

The choice also can be driven by economics, other factors being equal. Copolymers with multiple useful properties, for example, generally are more expensive than monolithic (single) plastics, which contribute fewer goodies, but may suffice.

Regardless of the adhesive used, a number of flaws can occur if laminating is not conducted properly. Poor clarity is a common fault caused by contaminants, particularly on the laminator rolls; low laminating temperatures and pressures; and poor web-to-web adhesion. Poor contact between substrates in the nip rolls or irregular application of adhesive are also responsible for faulty laminations.

To test the adhesion of a coating on film, scratch or cut the coating; then place pressure-sensitive tape over the scratch and perpendicular to it. When the tape is removed rapidly, the coating should not come off with it.

Curl in either the cross- or machine-direction and wrinkling can make a web impossible to handle. These flaws have a number of sources including unequal web tension and sometimes even the adjustment of temperatures and tensions to improve clarity.

As with any packaging material, vendors should maintain a careful quality control program and end users should have an equally vigilant quality assurance team.

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Chapter 5— Bags, Sacks, and Pouches

Introduction

Perhaps the oldest form of packaging and one that is still growing in use with renewed popularity, is the bag. It performs all the basic functions of packaging—containment, protection, and communication—generally at the lowest possible cost. It is created in a wider range of sizes and materials than any other packaging form. It is used for virtually every type of product from liquids and powders to solids and, therefore, offers a versatility unmatched by any other type of product container.

The bag got its start in the form of sewn animal skins and bladders used by ancient man for carrying water, wine, cheese, and other subsistence items. In more recent times with the advent of textiles and then papers and plastic films formed on high-speed machines, bags have become so generally available they are staple household and industrial items. It is estimated that annual U.S. usage of all papers, plastics, and foils in such flexible containers approached 6 billion lb (2.7 billion kg) in 1995 [1]. Of this total, film bags account for about 4.2 billion lb (1.9 billion kg), paper requires another 1.5 billion lb (680 million kg), and foil makes up the balance of 235 million lb (106 million kg). The number of bags obviously runs to many billions per year.

While textile bags have largely been overtaken by other materials, burlap and cotton still are used to form sacks for seeds, grains, and granular products. For export shipment of more moisture-sensitive products like sugar, the cloth can be laminated to PE for added barrier properties, but more likely is used with a liner.

More recently, material choices have broadened to include nonwovens where plastic fibers are compressed and bonded together in a process similar to "felting." Another recent development is the use of woven strands of plastic, particularly polypropylene (PP), for giant flexible sacks, which have pallet-sized footprints, but range in height from 12 in. (30.5 cm) to about 6 ft (183 cm) with capacities up to 6,000 lb (2,722 kg). Rectilinear or tubular in shape, the big bags can have either an open or closed top fitted with a woven filling spout. The bottom can be solid and is slit to dispense product or fitted with a woven discharge spout or even a fully openable bottom flap closed with ties (see Figure 5.1) [2]. Loops at the top enable transport on fork-truck tines. Properly loaded and handled, the big bags can stand alone and be stored in warehouse racks.

The bag structure can be porous, coated, or film-lined depending on barrier requirements. Some designs have heavy-duty, removable film liners, which can contain liquids. Depending on the product for which they are used and the nature of the liners, the sacks may be reusable. However, most are one-way containers that occupy less space in disposal areas than comparable rigid containers. Although relatively new, big bags already are used for a wide range of food, chemical, and pharmaceutical products and the business is growing more than 20 percent per year, say suppliers.

Before proceeding further, it is necessary to define terms. A bag has been described as a preformed container created from a tube of paper, plastic film, textile, or nonwoven material with one or both ends closed and an opening for loading product.

Bags either have one open end (open-mouth bag) or are closed at both ends and filled through a small opening at the side of one end called a valve. In recent years, bags also have been created with closures mounted in the face surface. These generally are used in conjunction with a paperboard or corrugated box (bag-in-box). Note also that some bag structures have gussets (pleats) in the sides that provide more filling room in the same width and length.

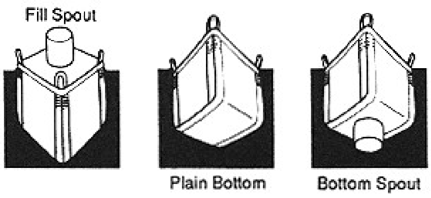

Figure 5.1.
Capable of holding thousands of pounds, giant sacks are designed with a five-to-one safety margin and offer a variety of filling and dispensing options including the ones shown. (Source: U.S. Sack Corp., Grand Junction, Colorado, used with permission.)

Consumer bags contain a standard unit of merchandise and serve as a shelf package at the retail level. These "small bags" generally are limited to weights up to 20 lb [3]. Larger industrial bags, particularly 50 lb and above, are termed shipping sacks.

A specialized design is the "baler" bag, usually a satchel-bottom or selfopening structure used to hold several smaller bags of product.

A pouch is a small flexible container made from paper, plastic, or foil materials, which is formed, filled, and sealed on a single machine. While still generally true, these definitions have been somewhat modified by development of single machines that form, fill, and seal industrial-size plastic "pouches" from rollstock and by machines that fill and seal small preformed paper and plastic "bags" that are constructed like pouches.

An envelope is defined as a die-cut flexible container with two faces that is joined by three flaps to form a three-sided enclosure that is open on the fourth edge for filling and can be closed by a gummed flap, tie string, or clasp. Because of the die-cut flaps, envelopes are folded differently from bags and are made on a completely different type of machine. Some envelopes are multilayer, containing a thick inner cushion of pulp paper or bubble-plastic. Such envelopes are used as packages in the rapid-delivery mailing systems mostly for small items or small quantities of product. Common envelopes often are used to hold instructions for packaged products of all sizes.

Advantages and Disadvantages

Bags and their flexible cousins generally have the lowest unit cost of any packaging form. They also keep shipping costs to a minimum since they have the lowest tare weight ratio (weight of package to weight of contents). Bags can be tailored to fit snugly around the products they contain and, beyond this, will adjust to any shift in the shape of the contents. A fluffy product, which tends to settle on standing, for example, will take up less space in storage because the bag settles with the product. Bags take up a minimum of space in storage and shipment, both before and after filling. Sizes can be made to suit almost any conceivable product and, when empty, they occupy the least amount of space in disposal bins and landfills. The latter has resulted in a new burst of enthusiasm by consumers and great growth in standard and new forms of pouches and bags that will be discussed in this chapter.

On the negative side is the nonsupporting character of standard bags. They may not stand as neatly on store shelves or at dispensing locations as more rigid types of packaging, and the wrinkles and folds may be unattractive for certain marketing purposes. Stacking in the warehouse or in a retail display may also present problems of slippage.

Durability is sometimes borderline, in some instances, deliberately so. On the other hand, it is possible to strengthen a bag to almost any degree by incorporating additional plies, scrims (latticework layers of plastic fibers), and/or tough film laminations. This type of reinforcement adds considerably to the cost, but for very expensive or hazardous products, export shipments, and the armed services, it is sometimes necessary.

Finally, some styles are not siftproof or suitable for variable density products.

Types of Paper Bags

There are three basic types of paper-bag construction: single-ply; duplex, or two-ply; and multiwall (three to six plies). Multiwall paper bags started with duplex structures, which sometimes included a paper/asphalt/paper laminate between the paper plies to add strength and environmental protection. This simple start has since been expanded to include coated papers, film, and foil layers, as needed, to protect products that today can include bulk shipments of pharmaceuticals and other delicate or hazardous chemicals from damage or from the atmosphere.

Plies in a multiwall bag are described in a numbered sequence that runs from inside to outside and only the paper plies are counted. The paper is further identified by the number of sheets used and their basis weight, the weight of 500 sheets, measuring 24 36 in. (61 91.4 cm) and totaling 3,000 ft^2 (278.7 m^2). Typical weights of kraft paper used for multiwall bags include 40, 50, 60, and 70 lb (18.1, 22.7, 27.2 and 31.8 kg). This is expressed as a fraction: number of sheets/basis weight. Different weights normally are not mixed, but when required by regulations or other needs, no more than two should appear in one bag. When mixed weights are present, light plies should be sandwiched between heavier ones (1/60, 2/50, 1/60) or the heavier wall should be outermost (3/50, 1/60). It should be noted that a 4/50 structure will be stronger than a 1/200 because as a general rule, two or more thin sheets are more serviceable than one thick sheet of equivalent weight. Not only are multilayer constructions more flexible, but the forces seem to be more evenly distributed and less concentrated. The outer ply, however, should not be less than 60-lb (27.2-kg) basis weight to resist snagging.

Paper bag terminology often is expressed in a kind of shorthand notation. Some common abbreviations are listed in Table 5.1. Consumer styles of paper bags typically are made from 50 to 80 lb (22.7 to 36.3 kg) bleached kraft. Styles include a pasted self-opening sack (PSOS), a heat-sealed version of

TABLE 5.1. Abbreviations Used in Conjunction with Multiwall Bags

AL	Aluminum Foil
AOP (AOPP)	All Over Perforations (Pinhole)
BL	Bleached Kraft
BTB	Bottom (Fold) to Back
BTF	Bottom (Fold) to Face
CK	Crepe Kraft
CKTIS	Crepe Kraft Tuck-in Sleeve
EXT	Extensible
FBS	Finished Bag Size
FCS	Freight Classification Stamp
FL	Finished Length
FT	Flat Tube
GP	Greaseproof
IRT	Insect Repellent Treated
MP	Moistureproof
MR	Moisture Resistant
MVTR	Moisture-vapor Transmission Rate
NK	Natural Kraft
1S1C	Side - 1 Color
PE	Polyethylene
PHP	Pinhole Perforations
POM	Pasted Open Mouth
PBOM	Pinch Bottom Open Mouth
PP	Polypropylene
PV	Pasted Valve
PVE	Pasted Valve Stepped End
PVSE	Pasted Valve Stepped End
SB	Satchel Bottom
SG	Staggered Gussets
SOM	Sewn Open Mouth
SOS	Self-opening Style
SOT	Sewn Over Tape
SV	Sewn Valve
TBW	Total Basis Weight
TIS	Tuck-in Sleeve
TOS	Tape Over Sewing
ULH	Upper Left Hand
URH	Upper Right Hand
UVP	Under Valve Perforations
VTB	Valve (Fold) to Back
VTF	Valve (Fold) to Face
WK	White Kraft
WS	Wet Strength

Source: Stone Container Corp., Chicago.

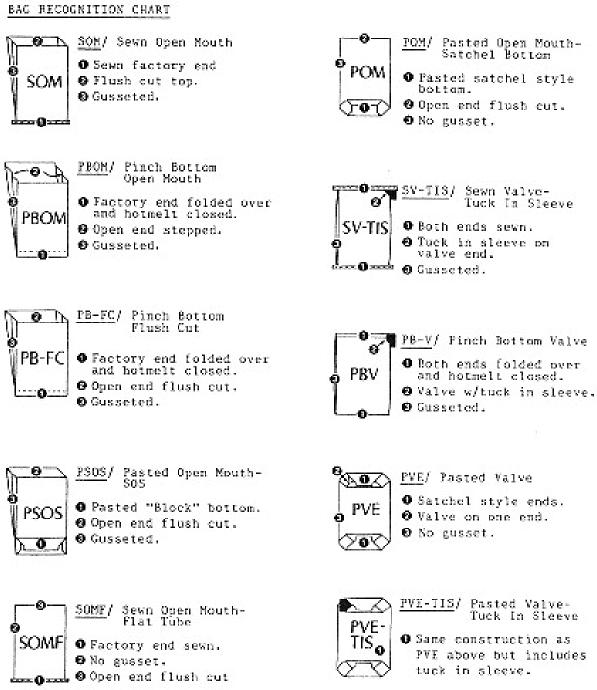

Figure 5.2.
Multiwall bag styles are described by closure method and other identifying characteristics.
(Source: Stone Container Corp., Chicago, used with permission.)

the PSOS, a satchel bottom, a pinch bottom (PBOM), and a sewn open mouth (SOM) (see Figure 5.2).

Multiwall shipping sacks have even more variations including: sewn open mouth (SOM); pinch bottom open mouth (PBOM); pinch bottom flush cut (PB-FC); pasted open mouth-SOS; sewn open mouth flat tube (SOMF); pasted open mouth-satchel bottom (POM); sewn valve-tuck in sleeve (SV-TIS); pinch bottom valve (PB-V); pasted valve stepped end (PVE) and

TABLE 5.2. Multiwall Bag Styles and Prices.

Style	Bag Size	Cost
Sewn Open Mouth	16 4 32	100%
Sewn Valve (TIS)	15 5 30	117%
Pinch Bottom	16 4 32	103%
PSOS	16 4 30	113%
Pasted Valve (Upper Insert)	20 24 - 5 T & B	112%
Pinch Valve	15 5 30	134%

Source: Stone Container Corp., Chicago, used with permission.

pasted valve-tuck-in sleeve (PVE-TIS) (Figure 5.2). Costs vary as shown in Table 5.2.

Pasted constructions typically use starch or dextrin adhesives, although hot melts have been used in recent years where great integrity or strength is required. Other closing techniques include taping, stapling, tying, and sewing. In sewn paper structures, the bottom end is sewn through all plies of paper from a minimum of 0.5 in. (1.3 cm) to a maximum of 0.75 in. (1.9 cm) from the end. A strip of tape often is included inside or over the outside of the end to control product sifting.

Open-mouth bags can be filled very rapidly and are favored for large particulate products. Valve bags usually are employed for finely powdered products (to reduce dusting in filling operations) and are filled by sliding the tubular, projecting valve over a "horn" (nozzle) on the filling machine. To prevent sifting (leakage), the valve is then folded and tucked into the bag. There are three basic types of folds: flat, single corner, and double corner. The latter is shown in Figure 5.3. In extreme cases, the valve may be glued or coated with a thermoplastic and heat-sealed.

A pinch-bottom structure with the open-mouth end folded and glued with hot-melt adhesive is used where the greatest integrity and siftproofness is

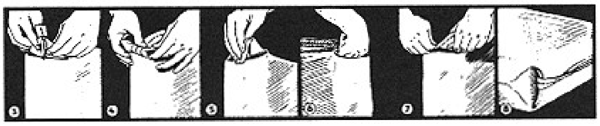

Figure 5.3.
Closing a valve type shipping sack with a double corner fold involves several steps. (Source: Paper Shipping Sack Manufacturers' Association, Tarrytown, New York, used with permission.)

demanded (see Table 5.3). This PBOM structure was created originally for shipment of U.S. food surpluses to third-world countries where rodent and insect pests and poor storage conditions demanded the ultimate in product protection. It is now widely used commercially.

The pasted-valve bag (PVE) has a stepped-end construction of plies that is securely pasted between plies with a waterproof adhesive. Spot pasting may be used between plies at the top end to facilitate opening for filling. These construction features result in a squared-up bag, which palletizes very securely and can be printed with product information on the side or end panels for easier product identification in pallet loads. These bags also offer improved surfaces for graphics, which has led to use of coated papers as outer liners. For retail products—where bags up to 50 lb (22.7 kg) are not uncommon in garden and lawn-care, pet food and litter products—use of high-quality flexographic and even rotogravure printing is on the rise. Better printing is a trend even among shipping sacks.

In multiwall shipping sacks, kraft, the strongest and cheapest type of paper, usually makes up the bulk of the plies. Semi- or full-bleached kraft on the outside improves the appearance of the finished sack at a slight additional cost (see Table 5.4). For greaseproofness, one ply of glassine paper could be included. For moisture protection, a paper/asphalt/paper laminate between plies of paper generally is the least expensive choice, but stiffens in cold weather. It also tends to gum up the sewing needles and with products that are packed hot, the asphalt may bleed through.

Polyethylene (PE) coatings or free films are much better moisture barriers than asphalt. They are increasingly used, but also more costly. Converting rigors require thicknesses of at least 1 mil. Although pound for pound, identical density film and coatings offer the same barrier on flat samples, converting damage can decrease coating performance in real life. So, deciding between a film or coating depends on film gauge, coating type, bag structure, and cost/performance issues.

Other barrier options include films such as polyester, PP, polyvinylidene

TABLE 5.3. Multiwall Bag Closure Styles (in descending order from most sift-resistant).

Heat Sealed Pinch Bottom Bag
Heat Seal Sewn Bag
Standard Pinch Bottom Bag with Inner Barrier Ply
Heat Sealed Tape over Sewing SOM style
Pasted Valve Bag with Inner Barrier Ply
Sewn Open Mouth Bag with Inner Barrier Ply

Source: Stone Container Corp., Chicago, used with permission.

TABLE 5.4. Costs of Different Multiwall Bag Structures (based on 16 × 4 × 32 SOM, 4/50 NK, 200 lb total basis weight).

Structure	Percentage
4/50 NK	100
5/40 NK	111
3/50 NK, 1/50 BL	117
4/50 EXT	108
3/50 NK, 1/50 Wet Strength	102
1/32 lb GP, 4/50 NK	161
3/50, 1/50 - 200 PE Overprint	145
1/C-50, 50 NK, 3/50 NK	123
1/C-150, 50 NK, 3/50 NK	132
1-C-300, 50 NK, 3/50 NK	145
0.5 HDPE, 4/50 NK	118
1.0 HDPE, 4/50 NK	133
1.0 LDPE, 4/50 NK	127
2.0 LDPE, 4/50 NK	150
1/0.45 BOPP, 4/50 NK	144
1/0.75 BOPP, 4/50 NK	157
1/0.75 Saran-coated BOPP (C2S), 4/50 NK	187
1/1.5 mil Saranex 10, 4/50 NK	229
1 Tyvek (1.3 mil), 4.50 NK	275
1/2.5 mil Valeron, 4/50 NK	266
1/4.0 mil Valeron, 4/50 NK	303
1/30 PE, 35 Foil, 15 PE - 50 NK, 3/50 NK	320
1/6 PE, 35 Foil, 6 PE - 50 NK	264

Source: Stone Container Corp., Chicago, used with permission.

chloride (PVDC)-coated PE, PVDC coextrusions, greaseproof paper, glassine, vegetable parchment, paper/cellophane laminates, wax paper, which gives excellent odor and moisture protection, metallized film or paper, and aluminum foil, usually in gauges of 0.00035 or 0.0005 in. (9.0 to 12.8 m). Foil is considerably more expensive, but nearly a perfect barrier for water vapor and gases. Selection is dependent on the type of protection needed (see Table 5.5) [4]. Some typical barrier structures are shown in Table 5.6.

In any given construction and surrounding atmosphere, a bag will absorb moisture at a constant rate. If this cannot be tolerated and atmospheric conditions cannot be changed, then the bag construction must be improved (see Figure 5.4).

The barrier material is generally put on the inside, as close to the product as possible, to avoid puncture from the outside. When directly against the

TABLE 5.5. Selecting Materials for Barrier.

Material	Moisture	Grease	Odor
High-density Polyethylene	X	X	
Low-density Polyethylene	X		
Linear-low-density Polyethylene	X		
Polypropylene		X	
Oriented Polypropylene	X	X	
Greaseproof or Glassine Paper		X	
Polyethylene-coated Kraft	X		
Metallized Film	X	X	X
Nylon		X	X
Polyester	X	X	X
Polyvinylidene Chloride	X	X	X

Source: Paper Shipping Sack Manufacturers' Association, Inc., Tarrytown, New York, used with permission.

product, it often helps it slide out of the bag, too. Barrier properties also are affected by closure style with heat-sealed pinch bottom bags being the most effective (Table 5.3).

Other special materials are fiber-free plies consisting of either a highly calendered or a coated paper to maintain the purity of critical products; exten-

TABLE 5.6. Barrier Material Gauge/Basis Weight (approximate).

Description	Gauge (mil, in.)	Basis Weight (per 3000 ft^2)
Polyethylene	1.0 (.001)	14.5 lb
Polypropylene	1.0 (.001)	14.0 lb
Polyvinylidene Chloride	1.0 (.001)	26.5 lb
Ionomer	1.0 (.001)	14.0 lb
Aluminum Foil	1.0 (.001)	43.0 lb
Aluminum Foil	0.5 (.0005)	22.3 lb
Aluminum Foil	0.35 (.00035)	14.7 lb
Coextrusion	1.5 (0.0015)	24.4 lb
Polyester	1.0 (.001)	20.2 lb
Valeron	Averages	13.7 lb/mil
Tyvek 1042		27.3 lb
Tyvek 1057		33.6 lb
Tyvek 1072		46.2 lb

If yield (in.^{2}/lb) is known, divide into 432,000 in.^{2} per ream (3,000 ft.^{2}) for weight per ream.

Low-density polyethylene/polyvinylidene chloride/low-density polyethylene.

Source: Stone Container Corp., Chicago, used with permission.

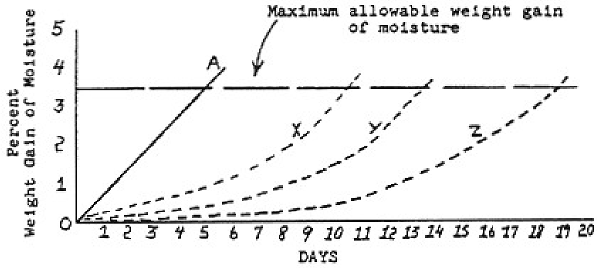

Figure 5.4.
To identify the barrier structure required, first determine with a current bag structure how many days it takes to absorb the maximum allowable water content, say 3.5 percent in 5 days (straight line A on chart). If this is not an acceptable storage time, then test additional structures (x, y, and z in chart) until one matches the requirements in both storage time and cost to achieve the desired 3.5 percent maximum water content.
(Source: Stone Container Corp., Chicago, used with permission.)

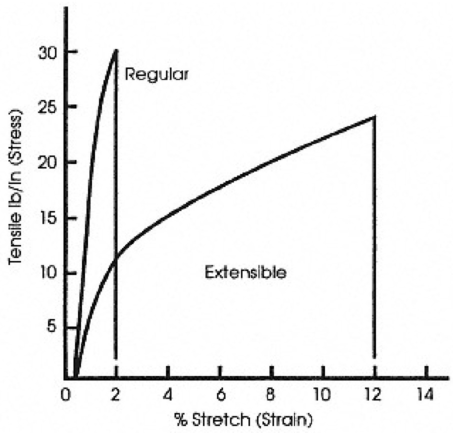

Figure 5.5.
Extensible natural kraft provides about 10 percent more stretch than natural kraft. (Source: Stone Container Corp., Chicago, used with permission.)

sible paper, which offers about 10 percent greater impact strength than regular kraft paper (see Figure 5.5); and uncalendered kraft paper or medium stretch crepe, which have less slip and strengthens a palletized load (see Chapter 2, Paper and Paperboard).

Unitizing is done by traditional methods such as strapping, shrink wrapping, and stretch wrapping or by spraying, brushing, rolling, or dispensing nonskid coatings and load-locking adhesives in overall or dot patterns.

Design Considerations

For thin products, a flat bag is the most economical style. If contents are bulky, side gussets or "accordion folds" will permit the bag to "square up" with less bulging.

TABLE 5.7. Bag Size Versus Volume.

Volume (ft^3)	SOM	PBOM	SV	PVE
3.39	20 4 50	20 4 50	19 5 48	25 40—5
3.29	20 4 49	20 4 49	19 5 47	25 39—5
3.20	20 4 48	20 4 48	19 5 46	25 38—5
3.05	20 4 47	20 4 47	19 5 45	24 39—5
2.95	20 4 46	20 4 46	19 5 44	24 38—5
2.86	20 4 45	20 4 45	19 5 43	24 37—5
2.77	20 4 44	20 4 44	19 5 42	24 36—5
2.68	20 4 43	20 4 43	19 5 41	24 35—5
2.60	20 4 42	20 4 42	19 5 40	24 34—5
2.52	20 4 41	20 4 41	19 5 39	24 33—5
2.43	20 4 40	20 4 40	19 5 38	24 32—5
2.34	20 4 39	20 4 39	19 5 37	24 31—5
2.26	20 4 38	20 4 38	19 5 36	24 30—5
2.18	17 5 41	18 4 41	18 4.5 38	22 33—5
2.10	17 5 40	18 4 40	18 4.5 37	22 32—5
2.02	17 5 39	18 4 39	18 4.5 36	22 31—5
1.93	17 5 38	18 4 38	18 4.5 35	22 30—5
1.84	17 5 36.5	18 4 36.5	18 4.5 34	22 28.5—5
1.76	17 5 35.5	16 4 39	17 5 33.5	22 27.5—5
1.69	17 5 34.5	16 4 38	17 5 32.5	20 30—5
1.61	16 4 37	16 4 37	15 5 35	20 29—5
1.55	16 4 36	16 4 36	15 5 34	20 28—5
1.48	16 4 35	16 4 35	15 5 33	20 27—5
1.42	16 4 34	16 4 34	15 5 32	20 26—5

TABLE 5.7. (continued).

Volume (ft^3)	SOM	PBOM	SV	PVE
1.36	16 4 33	16 4 33	15 5 31	20 25—5
1.30	16 4 32	16 4 32	15 5 30	20 24—5
1.24	16 4 31	16 4 31	15 5 29	18.5 25.5—5
1.18	15 3.5 32	14.5 4 32	15 3.5 30	18.5 24—5
1.12	15 3.5 31	14.5 4 31	15 3.5 29	18.5 23—5
1.06	15 3.5 30	14.5 4 30	15 3.5 28	18.5 22—5
1.01	15 3.5 29	14.5 4 29	15 3.5 27	18.5 21—5
0.96	15 3.5 28	14.5 4 28	15 3.5 26	16 25—5
0.91	15 3.5 27	14.5 4 27	15 3.5 25	16 24—5
0.86	15 3.5 26	14.5 4 26	15 3.5 24	16 23—5
0.81	14 3 27	14.5 4 25	12 4 27	16 22—5
0.75	14 3 26	13 3 28	12 4 26	16 21—5
0.71	14 3 25	13 3 27	12 4 25	16 20—5
0.67	14 3 24	13 3 26	12 4 24	14 23—4
0.63	14 3 22.5	13 3 24.5	12 4 22.5	14 21.5—4
0.59	11 3 27	11 3 27	10 4 25	14 20—4
0.54	11 3 25.5	11 3 25.5	10 4 23.5	13 20.5—5
0.50	11 3 24	11 3 24	10 4 22	13 19—5
0.46	11 3 22.5	11 3 22.5	10 4 20.5	
0.45	10 3 24	10 3 24		
0.42	10 3 23	10 3 23		
0.39	10 3 22	10 3 22		
0.36	10 3 21	9 3 23		
0.34	10 3 20	9 3 22		

Filled thickness.

Source: Stone Container Corp., Chicago, used with permission.

Length and width should have a ratio close to 2:1 so sacks will interlock on a pallet when each layer is turned 90 and thus make a neat, stable load without wasting space. However, some packaging engineers prefer a shorter bag with a ratio of 1.5:1 because it is easier to handle. A gusset can be any convenient size, but usually is around one-fifth the width, or between 3 and 5 in. (7.6 to 12.7 cm). For face widths over 24 in. (61 cm) or finished lengths over 48 in. (122 cm), check with the supplier to be sure the size is not beyond the range of its machines. The size of a sack for a particular product will depend on the product's density, entrapped air content, and flow qualities. Bag sizes versus volume are charted in Table 5.7. The only sure way to determine correct dimensions is by trial and error; making up a sample, filling it, and adjusting the measurements accordingly. Note that dimension descriptions vary depending on the bag style (Figure 5.6).

Consumer bag styles used for retail packaging generally hold less than 20 lb of products such as sugar, salt, popcorn, chemicals, pet food, grits, rice, cookies, coffee, cat litter, plant food, and insecticides. For consumer bags, the PSOS style is probably most widely used. The square bottom sets up well

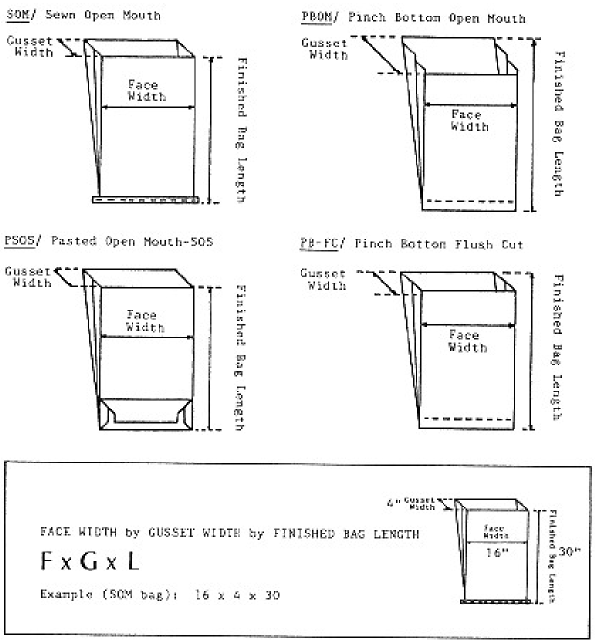

Figure 5.6.
Bag style governs how measurements are described. For example, SOM, PBOM, PSOS, and PB-FC styles are measured face width by gusset width by finished bag length. Valve bags use the same measurements plus note the valve size. SOMF bags are measured face width by finished bag length. POM bags also use face width by finished bag length plus notes bottom width. (Source: Stone Container Corp., Chicago, used with permission.)

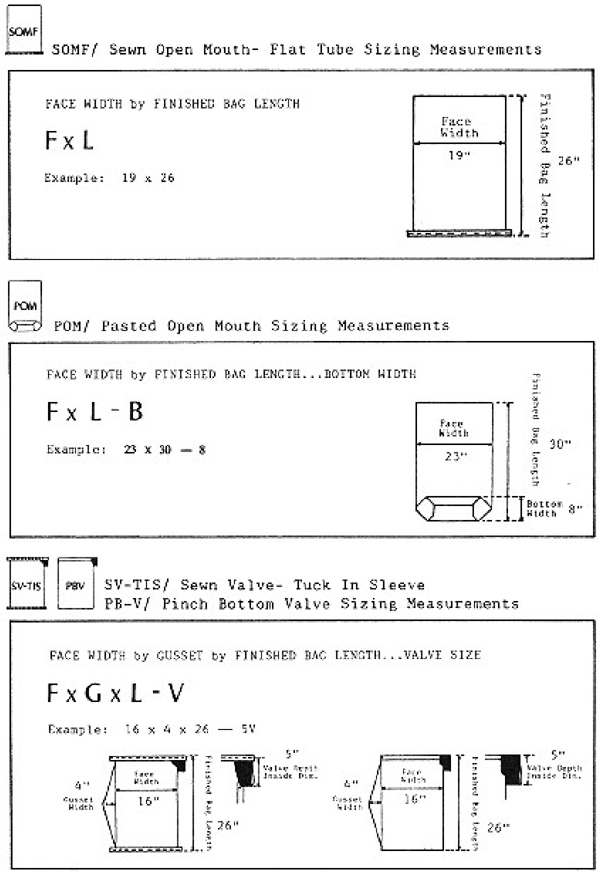

Figure 5.6.
(continued). Bag style governs how measurements are described. For example, SOM, PBOM, PSOS, and PB-FC styles are measured face width by gusset width by finished bag length. Valve bags use the same measurements plus note the valve size. SOMF bags are measured face width by finished bag length. POM bags also use face width by finished bag length plus notes bottom width. (Source: Stone Container Corp., Chicago, used with permission.)

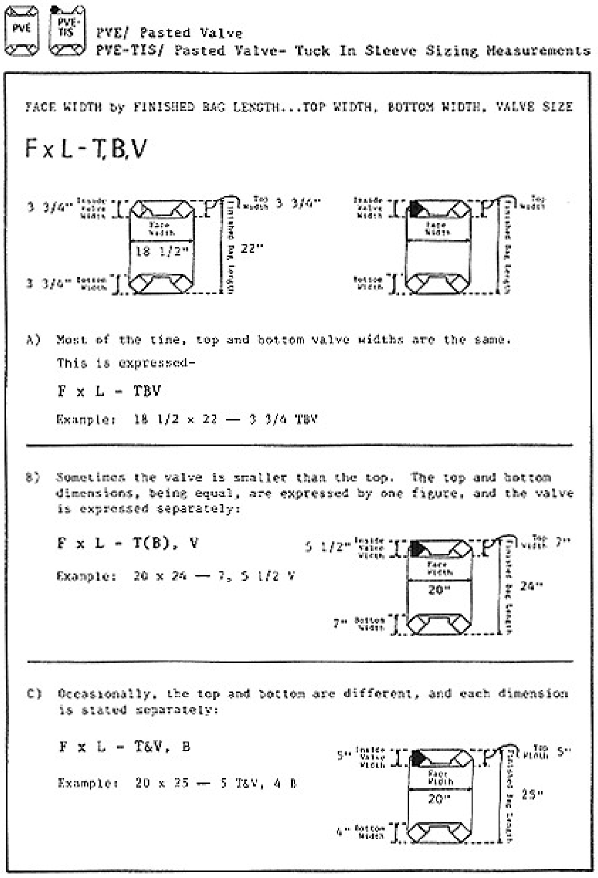

Figure 5.6.
(continued). Bag style governs how measurements are described. For example, SOM, PBOM, PSOS, and PB-FC styles are measured face width by gusset width by finished bag length. Valve bags use the same measurements plus note the valve size. SOMF bags are measured face width by finished bag length. POM bags also use face width by finished bag length plus notes bottom width. (Source: Stone Container Corp., Chicago, used with permission.)

for filling and provides a good billboard for store shelves. When heat-sealed rather than pasted, it provides a totally siftproof, moisture resistant, and/or greaseproof bottom.

For multiwalls, SOM bags are cost effective, can be trimmed for variable density products, offer high packaging rates (15–20 per minute), and can include an easy-opening feature.

Sewing machines are relatively inexpensive and either part of an integrated filling/weighing system for high-speed operations or located for convenient manual bag closing, usually suspended by a suitable counterweight for easy handling.

The thread closes the ends is usually chain-stitched, and instructions showing which end to pull for opening should be included in the printed copy. Where alkali is present, oil-dipped cotton thread should be specified for the stitching. In the case of strong acids, polyester thread is recommended. Adding a thick filler of soft cotton with the sewing thread improves the sift-proofness of a sewn sack by plugging needle holes. A 90-lb (40.9-kg) creped kraft paper tape folded over the end before sewing keeps the thread from tearing out of the bag. For moisture protection, tape over sewing (TOS) is superior to tape under sewing (TUS). In the latter case, the tape must be glued or heat-sealed in place, or adhered with a pressure-sensitive coating. With kraft paper tapes available in several standard colors, products can be color-coded, if desired.

Valve styles require no equipment for closing because both ends are closed by the sack manufacturer. However, a special filling machine with a horn (nozzle) that fits through the valve opening is needed. One operator can service two filling machines, since it requires only sliding the bag on and off the horn to complete the operation while the bottom of the sack rests on a table. The pasted sack is neater looking than the sewn sack, because it fills out to a squarer unit, and product identification can be printed on the top and bottom more easily. It is not quite as strong, however, but with stepped-end construction, in which the ends of each individual ply are glued to themselves, it is quite serviceable.

Export multiwall sacks usually are made with five or six plies of paper having a total basis weight (TBW) ranging from 270 to 350 lb (122.5 to 158.8 kg) with a moisture barrier and a wet-strength outer ply, even if the product is not hygroscopic. Domestic sacks, on the other hand, usually have three to five plies with a TBW of 140 to 280 lb (63.5 to 127 kg).

The weight of the product in a sack should be between 50 and 80 lb (22.7 and 36.3 kg) for convenient handling. Although 100-lb (45.4-kg) sacks are fairly common, they are too heavy for one person to pick up easily and should be avoided. With back injuries a leading industrial problem in the United States, today, two Washington, D.C.-based organizations, the Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH), have looked at ways to determine safe lifting weights. OSHA's proposed ergonomic rule is unlikely to be implemented any time soon, but NIOSH published an *Applications Manual for the Revised NIOSH Lifting Equation* in 1994. The new equation lowers the load constant from 90 to 51 lb (40.8 to 23.1 kg) and takes into consideration a number of factors including horizontal distance of load from the body, height of hands from the floor, vertical travel distance between pickup and put-down, frequency of lift, twisting and turning, and quality of handhold.

With any size of container, a certain amount of damage is bound to occur in shipment, and the extent to which the package should be overdesigned to prevent leakage depends on the value and hazard level of the product. For low-cost items, such as building materials, a 0.5 to 1 percent breakage is often considered acceptable, and a few empty sacks are included with each railcar or truckload to repackage materials from broken sacks.

Paper is sensitive to atmospheric conditions and should be stored, on the average, at about 70 F (21 C) and 50 to 60 percent RH, which will provide a moisture content of about 6.5 percent, keep the bags flexible and strong, and prevent embrittlement.

Never store bags in a hot, dry room or near heaters or close under warehouse roofs. Also avoid storage temperatures below freezing, which also tends to draw moisture out of the paper.

If plant construction is not proper for bag storage, it is actually profitable to construct a bag storage room with the necessary humidification or dehumidification equipment. The result will be much greater running efficiency on bag equipment.

Finally, there are a number of freight rules to be considered. These are described more fully in Chapter 20, Laws and Regulations.

Types of Plastic Bags

Plastic bags require completely different types of equipment both for manufacturing and sealing. They can be made from either tubular or flat film. Prices vary depending on the size of the bag and film gauge as shown in Table 5.8.

Tubular film requires only a simple cross seal to form a flat bag, which is open at the top end and can have side gussets (see Figure 5.7). A flat-film web can be folded over from both sides and joined in a centrally located "back-seam" construction that can be flat or side-gusseted. A flat-film web also can be folded in half and transversely seamed and cut off to form a series of flat or bottom-gusseted bags.

An advantage of this style is that one side of the film can be extended to form a lip, which makes the bag easier to open. The lip also can be punched

TABLE 5.8. Area Versus Cost for Small Polyethylene Bags (cost per thousand).

		Tubular Bag		Side-Weld Bag	
Size (in.)	Area (in.^{2}	1.25 mil	2.0 mil	1.25 mil	2.0 mil
3 6	18	$ 4.88	$ 5.97	$2.25	$ 2.75
4 6	24	5.42	6.50	2.50	3.00
3 10	30	5.96	7.59	2.75	3.50
4 12	48	6.25	7.92	3.75	4.75
6 8	48	6.25	7.92	3.75	4.75
8 10	80	8.75	12.00	5.25	7.25
6 14	84	8.75	12.50	5.25	7.50
8 14	112	10.83	16.25	6.50	9.75
10 12	120	11.67	17.08	7.00	10.25
10 14	140	13.33	19.58	8.00	11.75

Source: Crystal-Flex Packaging Corp., Rockville Centre, New York, used with permission.

and perforated so that a stack of these bags on a metal wire "wicket" can be fed into a bagging machine for automatic filling and sealing. Such "bags" generally are used for consumer products, particularly clothing items and other soft goods. As the bag is filled, it is detached at the perforations from the wicket and is then either heat sealed or closed with a twist-tie or plastic clip. It also can be closed with a "header," a folded and often printed paperboard sheet that is heat sealed, glued, or stapled over the end of the bag, forming a closure that also displays product information.

Industrial plastic bags made from heavy-gauge extruded tubular film are used for only about 10 percent of bulk packaging, because they tend to be more expensive than kraft-paper bags. In the early days, heatseal strength was a problem. However, advances in film coatings and/or addition of low-melting polymers and other film additives have greatly increased seal strengths (see Chapter 3, Films and Foils and Chapter 4, Coatings and Laminations). Plastic bags also can be very strong and quite easily formulated to provide a complete barrier, not only against moisture, but gas transmission, as well. A special cross-lamination of PE film has been devised specifically for bags of exceptional strength. It is created by combining two oriented films with the orientations placed at 45 to each other.

A problem with conventional flat plastic bags is securing them in pallet loads, since the film tends to be slippery. This is where new anti-skid coatings and palletizing adhesives play a major role, particularly with gusseted plastic bags that tend to square up better in such loads.

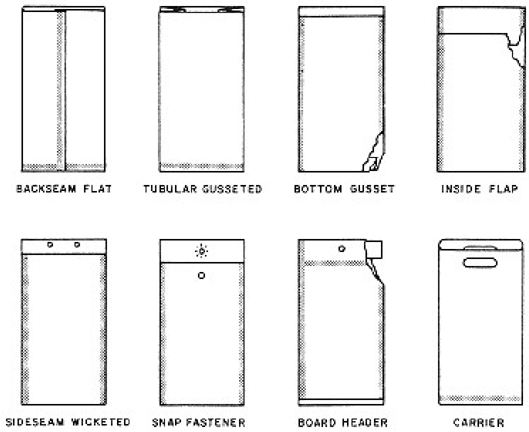

Figure 5.7.
Film tubing requires only a heat seal across the bottom to form a bag. The top is usually flush cut and may therefore be difficult to open. Side-seam bags can be made with a lip at the top for easier opening. Various attachments can be used for special purposes. See also Figure 3.12 in Chapter 3, Films and Foils, for forms of film in rolls.

Filling Methods

Methods for handling and filling products in bags include gravity, belt, auger, and impeller devices. Open-top bags are generally gravity filled by free flow, either from a net-weigh hopper or by supporting the bag on a weigh scale and filling it by gross weight. If a product tends to clump, a belt conveyor may be used to keep it loose in transport from the supply or weigh hopper to the bag. Hard-to-handle products are transported by an auger feed that forces the product into the bags.

Valve packers can use the above filling techniques for the same reasons or employ impeller or force-flow fillers to speed the operation. With the former, a rotating wheel forces product through the loading horn into the bag. The latter packer, also called an air packer, introduces air into the packer chamber to aerate the product.

The problem is that both methods introduce considerable amounts of air into the bag. Thus, air packers should be used only with perforated bags so the entrapped air can escape during storage, producing a flatter, more stackable bag profile. With an impeller packer, air-permeable filter valves should be inserted in the bag structure.

With both of these filling methods and also for products of very low density, a vacuum technique can be used to remove air during the filling operation and, thus, densify the product for easier, faster handling and more accurate net weights. For valve bags, the horn generally is connected to a weigher for gross-weight filling, although net-weight fillers also are used.

Types of Pouches

For purposes of this chapter, we will refer to bags of all sizes used for consumer quantities of product as pouches; and they are very much in vogue, today. As mentioned in Chapter 3, Films and Foils, consumers perceive film pouches to be a source reduction and to occupy little space in disposal facilities and landfills.

The most economical way to produce pouches is from rollstock on formfill-seal (FFS) machines in the packager's plant. There are several types of such machines. Vertical "pillow-pouch" machines form the film around a tube with a back seal and fill liquid or dry granular products through the tube. A double cross seal forms the top closure of a filled pouch and the bottom seal of the next pouch, the two being severed from each other by a transverse knife located in the sealing mechanism. Such machines can run at up to about 140 pouches per tube per minute.

A few of these machines seal fitments into the film web as it is fed into the machine, thus creating screw-top or valved dispensers for such special applications as bag-in-box liquid products. Recently, zipper-type devices have been developed and enable multiple opening and secure reclosure to protect remaining product. At first, the pouch film for such packaging was obtainable only with the zipper pre-applied. Now, however, rollstock zipper material can be applied to the film on the packaging machine. In addition, there is now a modified zipper that has a film extension. When heat-sealed, this added structure forms a tamper-evident seal, which is cut away by the consumer to access the zipper.

For small solid products, such as tablets and liquid dosages, twin sheets of flexible packaging materials up to about 20 in. in width are fed vertically through machines that heat-seal, fill, cross-seal, and slit rows of small pouches into individual four-side-seal packs at very high speeds.

"Flow wrappers" are horizontal machines that surround solid products with a film wrapper similar in structure to that produced on the vertical machine and can operate at speeds up to 1,000 per minute per lane.

Other machines fold film around flat products in a horizontal mode and heat-seal one edge and the ends. Another popular type folds the horizontally moving film web into a vertical position, spacing double, vertical heat seals to form a string of pouches that are cut apart after filling and top sealing at speeds up to 500 per minute. These three-side-seal pouches can be bottom-gusseted for larger fills and include the zipper-type reclosure feature.

Despite the popularity of FFS equipment, there is an increasing number of machines, today, that feed, open, fill, and close premade pouches, most particularly the newer stand-up designs, which are replacing some rigid containers for both granular and liquid products. The stand-up pouch gets its stability from stiff film and a bottom gusset that spreads to form a fairly stable base when the pouch is filled. Face- or corner-mounted plastic screw-cap or dispensing closures simplify use, particularly for liquids. All of these many types of pouches testify to the growing importance of this packaging form.

Pouch Applications

The potential for source reduction, economy, and customized designs targeted to specific products have made pouches an increasingly important part of the packaging mix in today's cost-and environmentally conscious world.

Without question in the United States, snack food and candies use the most pouches, ranging from simply printed PP film to elaborate structures containing various combinations of plain, white pigmented, and/or metallized polyethylene terephthalate (PET); PP; ionomer; ethylene vinyl alcohol copolymer; polyvinylidene chloride copolymer; foil; and paper materials (see Chapter 3, Films and Foils and Chapter 4, Coatings and Laminations).

Long used for individually quick frozen (IQF) vegetables, pouches have expanded to a variety of seafoods, dried fruits, cured meats and cheeses, snacks, and baked goods and for multi-portion packages of these products, increasingly feature resealable zippers. Another growing field is that ofpremixed salads, where controlled permeability is a necessity.

Other beneficiaries of the stand-up pouch are dry pet foods and refill quantities of some household chemicals. The stand-up pouches also are available with screw and dispensing fitments mounted in the face panels or at a top corner for liquids. However, Americans are leery of flexible packages for liquids and, as yet, have not adopted this package to any degree for such products.

When suppliers tried milk in liter-size conventional pouches in the United States a number of years ago, it died almost immediately, despite its popularity in Europe and Canada and the thriftiness of the package. Quarter-liter milk pouches now dominate the Canadian school-lunch program, but use in the United States is limited to a few school districts, mostly in border states where Canadian suppliers are trying to popularize this dairy package.

Pouches for dries—that is another matter. Refill containers of powdered cleaner and garden-care products have switched from rigid containers to conventional flat-bottom pouches or bags. Ground coffees, too, are marketed in both conventional and stand-up reclosable pouches. To withstand handling and preserve aroma, structures incorporating reverse-printed PET, foil, and linear-low-density polyethylene are used. For products with very sharp granules, a layer of biaxially oriented nylon is added as a cushion. Small pouches of dry soups and condiments, such as beef and chicken bouillon, also have made it with consumers for some years.

The institutional feeding field has no qualms about flexible packaging. For years, single-serving packets of condiments in laminated pouches have been used. Now, many kitchens receive liquid ingredients and sauces in bag-in-box quantities or pouch equivalents to No. 10 cans. Air is excluded in filling to preserve product flavor and the bag simply collapses as contents are withdrawn. Large bag-in-box structures are catching on in industry, too. Aseptic tomato pulp and sauce, for example, now are stored in bag-in-box structures that can hold up to 300 gal (1,136 L), a sizable jump for a package that was first created as an institutional container for Australian wines. Bag-in-box designs also are used for beverage concentrates, fruit preserves, and even a number of nonfood applications like chemicals.

Flexible packaging for food products must be high in barrier and rugged in its resistance to contents, distribution and handling rigors, and environmental conditions like refrigeration and freezing. In some cases, the structure must withstand radiation, chemical, and/or heat preservation/sterilization techniques as well.

In the United States, heat preservation of foods in pouches has been limited mainly to the retorted Meal Ready to Eat (MRE) rations developed by the Army and to “sous vide” foods, which are partially cooked under a vacuum and preserved during distribution by strictly controlled refrigeration temperatures. So far, neither process has captured the fancy of consumers. But a few regional attempts for the former at retail and for the latter in institutional outlets continue. Perhaps more common is the use of steam to sterilize the closure removal and replacement area of aseptic bag-in-box filling equipment.

Chemical sterilization has not been used for pouches or bags and basically is confined, at present, to hydrogen-peroxide treatment of cartons for aseptically filled liquids.

Radiation processing, although relatively common for medical products, has been limited for food to treatment of spices and products for astronauts and autoimmune patients with severe sensitivity to bacterial organisms.

Figure 5.8.
The Radura symbol must appear on packages containing irradiated food.

However, it should become a stronger factor because limited radiation treatment of poultry and fruits to reduce pathogens and spoilage organisms has been approved by the U.S. Department of Agriculture, Washington, D.C., as long as the packaged products carry a radiation symbol (Figure 5.8). Although some consumer activists criticize the use of radiation processing and a few jurisdictions have passed laws banning irradiated food, market tests of such products have been favorable.

Because radiation, chemical, or heat treatment can cause packaging materials to deteriorate, selection of structures for use under such conditions requires careful investigation and testing. Even though resistant materials tend to be more expensive, use of such treatments for food probably will increase due to the enhanced shelf life and safety aspects provided.

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Chapter 6— Folding Cartons and Set-up Boxes

Introduction

Probably the most popular of the various types of rigid packages is the folding carton. The reasons for its wide use are fairly obvious: It is very economical in material cost as well as in fabrication and assembly. Being collapsible, it takes a minimum of space in shipment and in storage and, when collapsed, in disposal containers and landfills.

The finest kind of printing and embossing can be used to make cartons very attractive, which adds value and sales appeal to the product. The versatility of these containers is evident in the range of sizes and styles possible, and the potential to include special features with little or no added cost by changing how the blank is cut.

The many functions that any package must serve—containing, protecting, selling, and transporting—are all performed very effectively by the paperboard carton. More than any other form of packaging, it has made possible modern self-service selection of branded merchandise, now a normal part of our way of life.

The characteristic that sets folding cartons apart from most other packages is that they can be creased and folded to form semirigid or rigid containers. Generally, they are made to be shipped and stored flat to save space and then erected at the point of filling. Since the same statement can be made for corrugated and solid fibre shipping containers, we need to be more specific in our description.

Folding cartons are usually much smaller than corrugated boxes—normally of a size that can easily be held in one hand. Furthermore, the word *carton* is generally reserved for the folding package, the term *box* is applied to the larger shipping containers and rigid set-up box constructions. Although boxboard actually is made from about 0.010 to 0.064 in. (10 to 64 points, 0.25 to 1.63 mm), thicknesses used for folding cartons usually run between 0.012 and 0.032 in. (12 to 32 points, 0.31 to 0.81 mm). Weights heavier than 32 points become very difficult to cut and score (crease) on standard equipment.

The type of boxboard used will vary in composition from filled sheets made from recycled or scrap materials to pure virgin pulp of the highest quality. However, all must have bending qualities that allow them to be creased and folded without cracking. Such "bender," as it is called, is made possible by adding such materials to the pulp as different kinds of softwood and hardwood fibres as well as waxes and resins, which size and bind the mix. When reprocessed materials are used, it is usually necessary to add some virgin pulp to impart the necessary strength for bending (see Chapter 2, Paper and Paperboard).

History

The earliest recorded use of paperboard packages dates to the beginning of the nineteenth century, when carpet tacks were put up in boxes shaped over wooden forms, held together with tacks stuck through the folded ends, and then tied with string. Known familiarly as a "paper of tacks," this was the forerunner of the folding carton as we know it today.

Paper boxes that were used in the 1840s required a great amount of hand cutting and gluing, and were used only for luxury items. However, a mistake by a pressman in setting up to print paper seed bags led to the technique that is now used to cut and crease paperboard. Faulty adjustment of the press caused the printing plate to cut through the paper instead of printing it.

The Robert Gair Company, to its credit, recognized the significance of this act, and after considerable experimentation, developed a method in 1879 for cutting and scoring boxes by machine instead of by hand. Previously the scoring had been done separately on a platen press, from which the ink rollers and fountains had been removed. The scoring die was made from brass printing "rule" (metal strips) locked into a "form" (platen), and the cutting was done separately with a guillotine knife. Robert Gair's contribution was combining the two operations on one machine.

The first major user of this new-style box was the National Biscuit Company (now Nabisco Biscuit, Paterson, New Jersey), which introduced an improved soda cracker called Uneeda Biscuit in 1897. To protect the flavor and texture, these new crackers were put into a folding box with a waxed paper liner and overwrapped with printed paper.

The package was invented by Frank Peters of the law firm of Green, Honore and Peters. The graphics were the work of his law partner Adolphus Green. The carton was a resounding success. Other manufacturers quickly followed suit, and the modern era of packaging as we know it today was on its way.

In retrospect, it is easy to see how this was so readily accepted: a good name, a bold design, convenient packaging, and intelligent advertising—all recognized today as the necessary ingredients of a successful marketing effort. But it took real genius and courage in those days, without benefit of agencies and consultants.

By 1923 there were 200 manufacturers of folding cartons, and today the number has grown to more than 440 plants. In 1994, these facilities shipped nearly 4 million tons of folding cartons (including gabletop containers) and

TABLE 6.1. 1994 Shipments by End Use (percent of total tons).

Food—Dry	24.0
Cake Mixes	2.4
Cereals	11.5
Pet Food	1.4
Gelatin	1.2
All Other	7.5
Beverage Carriers	15.4
Food—Wet	9.4
Frozen Food	5.0
Butter and Ice Cream	2.2
Meat, Lard & Margarine	1.6
All Other	0.1
Retail and Laundry	5.8
Paper Goods	5.4
Biscuits/Crackers	4.8
Soap	4.6
Perishable Bakery	3.4
Tobacco	3.3
Hardware	3.2
Candy	2.9
Medicinal	1.4
Cosmetics	1.4
Sporting Goods/Toys	1.1
Textiles	0.1
Miscellaneous & Beverages	0.1
Gabletop	13.0
Total tons	3,751,000

Source: 1994 Marketing Guide, Paperboard Packaging Council, Washington, D.C., used with permission.

recorded sales of more than $5 billion dollars [1]. About 95 percent of the cartons produced are made to the customer's specifications. Only 5 percent are what might be called stock cartons in standard sizes and styles for the small user. Table 6.1 gives a breakdown of various industries and the relative quantities of folding cartons used [2].

Advantages and Disadvantages

The features that make folding cartons useful for the packaging engineer are low cost, good strength properties, and excellent appearance on the retail shelf. In medium to large quantities, the folding carton generally offers the lowest cost of all rigid packages.

Several cartons can be printed on a single sheet and can be cut and scored at the same time in a succeeding operation. Mixed sizes or different graphics can be combined this way, in what is called a "combination run." Quantities can be adjusted by the number "up" on the sheet or by "drop-offs," in which the size of the sheet is reduced partway through the run to skip some of the ones on the end of the original sheet. There is no limit to the attractiveness of cartons, particularly those printed by offset and gravure techniques.

Since cartons are shipped and stored in collapsed form, the folding carton takes up a minimum of space, in contrast with other types of rigid containers that must be kept "erect" until used. Versatile in structure, a great variety of sizes and styles can be made with built-in platforms, windows, extended panels, curved scores, and many other novel features.

Mechanical handling of folding cartons is very efficient, and equipment is available to open, fill, and seal or close these containers at speeds up to 400 per minute.

On the negative side, the folding carton is rather flimsy in comparison with a set-up box or other rigid container. The strength of a folding carton is limited by the manufacturing process, which cannot easily cut paperboard that is much heavier than about 0.032 in. (0.81 mm). However, this deficiency can be offset by diecutting patterns that subsequently permit folding and gluing of the sheet into multiple layers. Generally, though, folding cartons are limited in product weight to just a few pounds.

The Materials

Paperboard used for folding cartons is made from "furnish" (the mixture of pulp, water, and additives fed into the paper machine) that is designed to produce a "bender" (paperboard that when properly scored and folded will

TABLE 6.2. Paperboard Grades Consumed in Folding Cartons in 1993.

Grade	Percentage
Solid Bleached Sulfate	25.4
Kraft, Plain white Lined or Coated	18.0
TOTAL Nonrecycled	43.4
Clay Coated Recycled (Waste Paper Filler)	41.7
Darker Recycled	9.0
Laminated	2.1
Other	3.8
TOTAL Recycled	56.6

Includes bending chip, mist, bleach manila and patent coated.

Source: Paperboard Packaging Council, Washington, D.C., used with permission.)

not crack at the outer fibres). There are different grades of board, depending on the requirements (see Table 6.2 and Chapter 2, Paper and Paperboard).

For food products or where a high grade of board is desired, it is best to use virgin material. This can be a solid sulfate or a sulfite board, which is a creamy white color all the way through. Although this is a high-priced stock, its strength and stiffness make possible the use of a lighter gauge, around 10 percent less in thickness than that of a filled board of equivalent strength (see Table 6.3 for a comparison of stiffness for different grades of boxboard).

The most widely used material for folding cartons is cylinder board, which is made up of several layers of pulp. The core is usually reprocessed scrap paper, with a layer of pure newsprint on one side and a skin of bleached virgin material on the other side. Better grades also have clay mixed with casein on the surface to give a smoother, whiter printing surface. As the quality goes up, so does the cost. However, it is false economy to choose a stock strictly on the basis of price, because an inferior board often will increase production costs by causing more machine downtime and a higher scrap rate.

To the environmentalist, everyone should be using nothing but recycled

TABLE 6.3. Density as a Factor of Stiffness.

Grade of Boxboard	Pound/Caliper point	Stiffness Factor
Solid Bleached Sulfate	4.1–4.4	100
Low-density Bleached Sulfate	3.7–4.0	88
Ultra Low-density	3.3–3.6	80

paperboard and, today, many packagers are switching to boards that have at least some post-consumer-recycled (PCR) content. But the choices are not so simple. As recycled board has become popular, its price has risen, too. There also may be trade-offs when it comes to print reproduction and machinability on the production and packaging lines.

In some product categories, notably high-priced toiletries and cosmetics, consumers judge a product's quality partly, at least, by the heft and gloss of its package. Some products, food and medical, for example, simply cannot be placed against recycled materials of unknown source and potential contamination. Although there is now at least one bleached board with up to 30 percent PCR that is acceptable for food contact.

What can a packager do? First, know what boards are available, learn how new technology is improving today's structures and determine what each type of board does the job best.

Virgin kraft is either a brown sheet, usually found in liners for corrugated or a bleached white sheet used mostly in folding cartons. The latter also is known as solid bleached sulfate (SBS) and is available in calipers from 10 to 28 points (0.25 to 0.71 mm). The largest usage is in the 14- to 18-point range (0.36 to 0.46 mm), but a fair amount is used up to 24 point (0.61 mm).

SBS dominates the food, pharmaceutical, toiletry and cosmetic, and other applications where superior strength, marketing appeal, and high-speed packaging-machine performance are of paramount importance.

Paperboard also is classified by density: low, medium, and high. Most SBS today is low density running from 3.2 to 3.6 lb/1,000 ft^2 per caliper point (15.6 to 17.6 g/m^2). Medium-density weights range from 3.5 to 3.9 lb/1,000 ft^2 (17.1 to 19 g/m^2) and high densities are from 3.8 to 4.0 lb/1,000 ft^2 (18.6 to 19.5 g/m^2). The heavier the board, the stronger and more expensive it is. Boards of the same caliper from different mills—or even from different paper machines in the same mill—can weigh differently, an important point for packagers to remember since different carton lots may require adjustments to cartoning machines.

Newsback is the second most important board in packaging. Historically, this recycled material is made from printed and unprinted newspaper stock; but, increasingly, it also now includes, in varying degrees, recycled cartons including unprinted and printed clippings, computer printouts and other office waste, and both virgin and old corrugated. The virgin scrap increases newsback's strength and performance.

Newsback generally is coated on one side, sometimes on both. In the latter case, the printable surface is bleached kraft with a clay coating. For the other side, a clay coating gives a fairly presentable appearance. This board is satisfactory for a broad number of packaging operations, but will rarely reduce costs and certainly is not a reduction in materials.

Recycled board is normally high density, 3.8+ lb (1.7 kg), since more of the weaker reused fibre is needed for strength and body. As a rule, recycled board needs to be about 2 points thicker to equal the strength of SBS.

Recycled newsback is strong in chemicals, hardware, paper products, and applications that run at moderate packaging speeds. However, it is gaining ground in toiletries and over-the-counter drugs, too.

A third material of choice, today, is solid unbleached sulfate (SUS), a thick, brown corrugated-liner board made on the fourdrinier. With a oneside (or rarely two-side) coating of bleached kraft and clay, it is known as coated natural kraft (CNK). It also can incorporate a wet-strength additive.

The material is very stiff, strong in moist conditions, and can be die-cut to form handholds because of its great tear strength. On the downside, the stiffness is tough on converting equipment where the board scores and folds with difficulty and rapidly dulls dies. SUS dominates the beverage-carrier field and other applications where great strength and moisture resistance are important. It also is said to be gaining in candy-bar trays and cartons and some frozen-food applications.

Starting in Europe and now pursued with vigor in the United States are newer practices for the creation of multilayer boards. By combining materials from various sources, a paperboard of lower or higher strength, lighter or darker color can be achieved to meet end-use requirements. It starts with segregation of recycled fibres, which then can be combined in layers or proportionately to achieve desired properties (Figure 6.1). As recycling of paper, paperboard, and corrugated waste has increased and collection methods improved, such segregation has become both possible and profitable.

Structures with a central core of recycled paper fibres sandwiched between layers of virgin kraft can achieve many of the properties of 100 per-

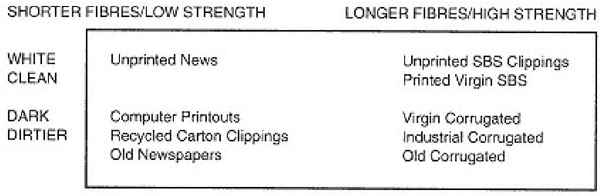

Figure 6.1.
Segregation of recycled fibre sources enables paperboard mills to mix or layer material to customize strength and coloring according to use and cost requirements.
(Source: Jefferson Smurfit Corp., St. Louis, used with permission.)

cent virgin board at less cost. While most recycled board is made on cylinder machines, the Inverform, Angel, and Ultraformer units, now available at a few mills, can lay down pulps in many thin layers and with much greater uniformity of strength in both the machine and cross-machine directions. Steaming calendar rolls, two or three top finishes with air-knife and rod coaters, and added plasticizers and binders produce smoother surfaces.

These advances have greatly improved the properties of recycled board. Nonetheless, experts still advocate, and even most environmentalists agree, that for the present, recycled board should not exceed 35 percent PCR material. Even at this percentage, some “shiners” and “glitches” (hard particles) remain to blunt cutting and scoring knives and reject ink coverage. Great attention must be paid to scoring, particularly with the grain. Wider scores help, but may be considered messy.

Inks, especially without the traditional heavy-metal pigments now viewed as an environmental no-no, must be carefully formulated for softer recycled boards. For best reproduction, check ink spread in absorbent areas and avoid large dark-color areas that tend to emphasize shiners. To showcase printing on the backside of recycled board, a lighter colored layer may be needed.

Although paperboard—virgin and recycled—is the most common carton material, sheet plastic has been used to a limited extent. Properly plasticized cellulose acetate or polyvinyl chloride make fairly good containers, but have a tendency to crack at the hinges and will not stand much abuse in shipment. Their advantage is transparency, and for luxury items a very glamorous presentation.

In one variation, the plastic is formed into a rectilinear tube that is combined with a paperboard tray to make a two-piece slide box. Plastic coatings or laminations of film or foil on paperboard provide an attractive, printable surface on the outside. For greaseproofness or some other barrier function, this side can be turned in.

Folding Carton Design

There are a great many variations in the construction of folding boxes. The most common style is the “reverse-tuck” carton in which the board is folded on four parallel lines, leaving a small overlap (manufacturer's joint) that is glued down to form a tube. The ends are cut and creased to provide flaps that cover and lock into the ends of the tube to complete the package.

A “seal-end” carton is similar except that the ends are glued after the box is filled. There are many variations in end flaps, as shown in Figure 6.2. Spe-

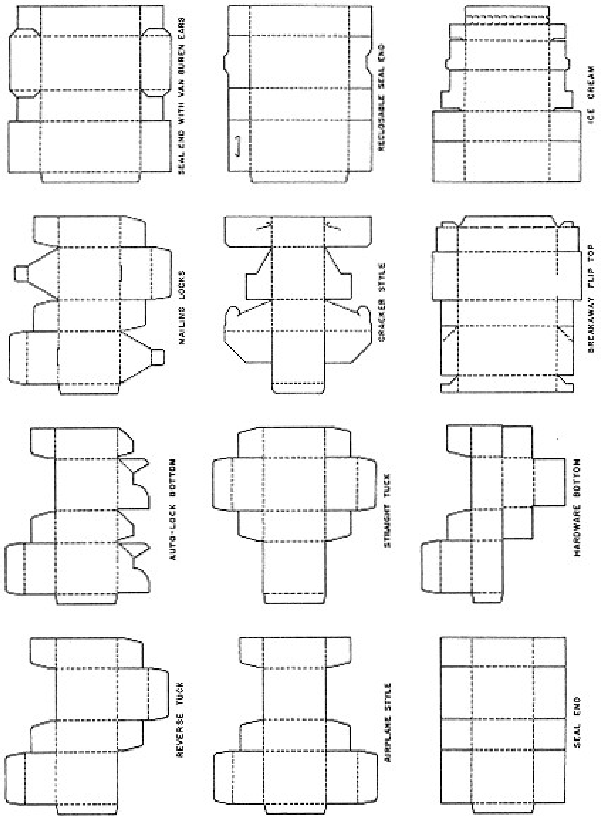

Figure 6.2.
There are a great many variations on these basic styles of folding cartons. These flat blanks have been cut and creased before being folded and glued. The glue flap usually is attached to the back panel, so that the raw edge at the opposite end will face to the back. The outside, or die side, is shown in these drawings.

cial locks are often put on bottom flaps to keep heavy objects from falling through when the package is picked up. Extra tongues and slots ensure mailing boxes will not open in transit.

The number of modifications, which can be made to the basic patterns, is limited only by the designer's imagination. Cutouts and extensions are used for increasing visibility or for holding objects in position. Perforations and hinges, tabs and slots, easels and sleeves can be incorporated in the design with little or no added cost. It is this versatility that makes the folding box such a useful package.

Choice of material and style of box will depend on the type of product and the market requirements for that particular item. If the package structure is strictly utilitarian, such as a shelf packer or an industrial or institutional unit, cost is the primary consideration. The problem then becomes one of finding the minimum square area of the lightest gauge that will serve the purpose.

The numbers in Table 6.4 and reference to the curves in Figures 6.3, 6.4, and 6.5 show how strength increases or decreases as the caliper changes. After specifications have been worked out, tests should always be made to prove out the design. Drop tests and vibration tests are particularly important and should be as realistic as possible, with the actual contents in place and full quantities packed in the intended shipping container (see Chapter 18 for more information on test methods).

If the folding carton also will be required to do a merchandising job, then other factors must be considered. The method of display is the first thing to take into account. On the dealer's shelf, the package must be stable so that it does not fall over easily. It should present a good face when it is stacked in mass display. It should be proportioned to give an impression of good value,

TABLE 6.4. Suggested Thickness of Boxboard for Non-Supporting Contents.

Volume of Carton (in.^{3})	Weight of Contents (lb)	Thickness of Board (in.)
Up to 20	Up to 0.25	0.018
20 to 40	0.25 to 0.50	0.020
40 to 60	0.50 to 0.75	0.022
60 to 80	0.75 to 1.00	0.024
80 to 110	1.00 to 1.25	0.026
110 to 150	1.25 to 1.50	0.028
150 to 200	1.50 to 2.00	0.030
200 to 250	2.00 to 2.50	0.032
250 to 300	2.50 to 3.75	0.036
300 to 375	3.75 to 5.00	0.040

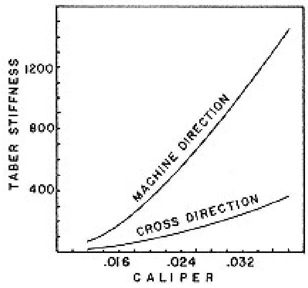

Figure 6.3.
Stiffness of paperboard is determined by the modulus of elasticity, grain, and cross section of the sheet. Wood pulp has a modulus of about 500,000 psi (3,448 MPa) in the individual fibres. Since most of the fibres are pointed in the machine direction, the stiffness is greatest in that direction. As the caliper of the sheet increases, the moment of inertia increases in proportion to the square of the distance from the center of the sheet to the outside surface. Outer plies therefore have the greatest effect on stiffness.

but should not be deceptive. Figure 6.6 shows how to find the correct size of a carton for a collapsible tube, for example.

The carton should fit between standard store shelves. If it is likely to be located on a pegboard rack, then a hang tab or an extended panel with a suitable hole will be needed. For the convenience of the consumer, the package should be easy to pick up and hold. A heavy carton can have a built-in handle. A window to show the contents or a good illustration of the product may help clinch a sale.

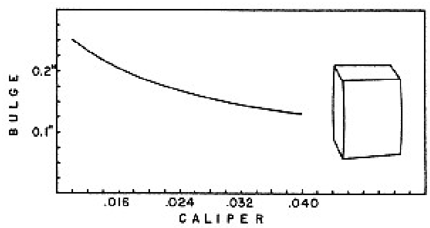

Figure 6.4.
Large cartons of granular products will bulge from the internal pressure of the contents. The area of the panel is the most important factor. As the chart shows, increasing the thickness of the paperboard has little effect on reducing the bulge.

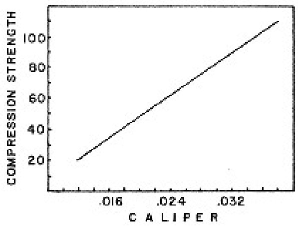

Figure 6.5.
Most of the forces exerted on a carton in shipment are compressive. The chart shows how the strength of a carton increases as caliper increases. This is based on the maximum top-to-bottom load in pounds that could be supported by a carton 8.25 by 3 by 11 in. (210 by 76 by 279 mm).

There are trends in package display, too. For a long time in retail outlets, wherever possible, cartons have been positioned (with appropriate printing) with the main panel facing outward and upward to get greater display impact. Alert packagers may even be able to use the same carton in a horizontal position for another company product that displays best in this posture and/or can be stacked two high. However, as the number of products required in stores has steadily increased, particularly in supermarkets, many store managers are trying to minimize such facings to gain more shelf space. The battle for display is constant.

A hard look should be given fifth-panel cartons. They do give extra shelf impact, but use more board and can be difficult to handle on-line and to load into shippers. However, for small items, such a container may be necessary to get any significant display impact at all.

To reduce pilferage, it may be necessary to enlarge the carton so that it cannot be palmed or hidden in another package. For the same reason, it is best to glue box flaps to deter pilferers from returning an empty box to the shelf.

The strength of the carton, quality of board and presswork all contribute to a good appearance on the shelf. It is poor economy to use inferior materials that quickly become shopworn.

Once marketing considerations have been acknowledged, then the rest of the material and design considerations should be based on cost/function needs—pursued a step at a time.

Since all mills produce different boards, a smart packaging engineer will first determine the marketing and physical requirements of the proposed package and source board that best meets such needs.

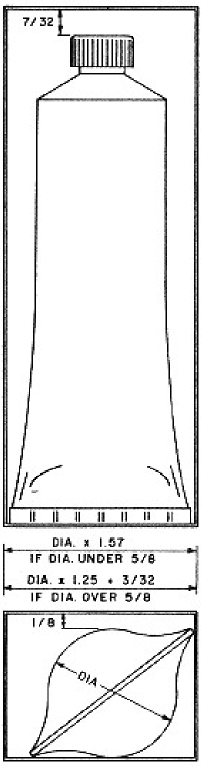

Figure 6.6.
The Bristol-Lund formula computes the correct carton size for a collapsible tube and normally meets requirements pertaining to deceptive packaging.

Next, he should be sure the choice will be available for awhile and in the required volume. For example, heavy recycled boards over 30 points in caliper (0.8 mm) are being phased out, as is very heavy SBS, except for milkcarton stock. Other boards such as 10-point (0.25 mm) and E- and F-flute corrugated (sometimes used in heavy-duty folding-carton applications) can be difficult to obtain, depending on geographic location. Another factor is weather conditions. Humidity, for example, can affect boxboard stiffness and carton strength (see Figure 6.7).

If recycled board is a choice, the packaging engineer also should calculate the costs of scrap in converting and printing, and possible lower performance on packaging machinery because, if speeds are high, performance may be low. In addition, such intricate structures as edge and tuck-and-tongue locks may not possess the needed strength. As a result, recycled boards may need to be thicker for adequate performance. However, this means heavier shipping weights and larger shipper sizes.

Even if early packaging is expected to be a hand or semiautomatic operation, it is well to look ahead and determine if the eventual goal will be automatic equipment. A snap-lock bottom carton, for instance, is ideal for manual loading, but impossible to close by machine. Instruction sheets, platforms, and filler pieces should be designed so that conversion to a more sophisticated operation will not require new cutting dies and printing plates or even new packaging equipment.

Cost is always an important consideration, and the choice of design and type of material to be used will largely control the final cost of the finished goods. In general, any improvement in the properties of the board stock or

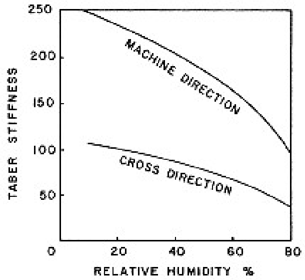

Figure 6.7.
Weather and storage conditions can reduce board stiffness by as much as one-half.

in the surface appearance will increase the cost. It is in this area that the packaging engineer can perform a service to the marketing department by helping them to reach decisions. There are no hard-and-fast rules in this kind of work, and the selection of the final design will require a great many compromises. Reference to Table 6.5 will help choose between a filled board and one made from all virgin material.

When it is all over, the bottom line is the cost of performance. Environmental considerations are popular now, but over the long run, most packaging experts agree, what works best and is most totally economical will win.

The packaging engineer also should work with the carton-company designer. In fact, the trend is to "mutually agreed-upon specifications" and a jointly acceptable plan for carton development. It takes time, say vendors and packagers alike, but is well worth it.

The essential points to be covered in specifications for folding cartons are (1) dimensions, (2) stock, and (3) presswork. The dimensions are always given in the order of length, width, and depth measured from center of score to center of score. The first dimension is along the hinge of the cover. The second is from the hinge to the tuck. The last is parallel to the glue lap. If style can be described accurately in words, then no drawing is required. However, with intricate designs, it is safer to make a detailed diagram.

Caliper of paperboard stock, its density or basis weight, coating, and brightness should all be spelled out. Both front and back surfaces should be designated, e.g., white machine clay-coated, newsback, bending boxboard, and so on. The type of printing should be specified. All colors and shades must be identified by swatches or standard numbering systems, along with allowable deviations from standard. A need for gloss inks and spot or overall varnish must be written into the specifications. Methods of sampling and ac-

TABLE 6.5. Comparison of Virgin Stock with Filled Board.

Property	Solid Bleached Sulfate	Reprocessed Filler
Bulge	Bulges when open owing to less stiffness in the machine direction	Stiffness is higher in the machine direction
Scores	Scores hold well	Scores reset with age
Creep	Slow rate of creep, less fatigue under compression	High rate of creep, more fatigue under compression
Gluing	Requires expensive resin	Can use low-cost dextrin glue
Uniformity	Machines more consistently	Less uniform results

ceptance quality levels should be detailed (see Chapter 19 for statistical sampling and testing by attributes).

At the outset of a specific project, the inside dimensions should be established as determined by the size of the object to be contained. A small amount of clearance—usually 1/32 to 1/16 in. (0.8 to 1.6 mm)—is added to each dimension of the article to be cartoned. Thickness of the stock is the next choice with 18- and 20-point (0.457- and 0.51-mm) boards the most commonly used gauges. A sample is best for confirming design dimensions at this early stage.

Today, most sizable carton manufacturers and even some packagers also have a design department and the work is done on a computer. With computer-aided design (CAD) and a digitizer mat, critical points of a carton drawing are plotted and entered into a data base. Then, the computer connects the dots with lines. The computer is also connected to a plotter, which can transfer the design to paperboard or a vinyl sheet. If transferred to paperboard, the plotter also can make the scores and cut out the blank to exact carton specifications. The sample can then be checked out by both packager and carton maker for final approval.

If the plotter transfers to vinyl, it can draw the image onto a clear polyester-film surface, which can be used as an overlay to make sure that the graphics are aligned to the carton structure.

Smaller packagers may still wish to make samples by hand. To prepare such a sample, mark the score lines and cuts on the back of a sheet of board in pencil. The grain of the board is nearly always made horizontal; that is, it runs around the box perpendicular to the main score lines. This avoids bulging along the top edge and helps main panels lie flat (see Figure 6.8).

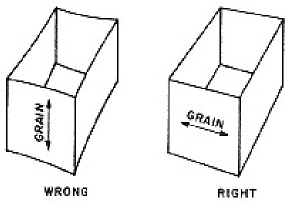

Figure 6.8.
Board grain usually runs around the box and perpendicular to the main scores. This provides more stiffness across the span from one score line to the other Folded edges provide stiffness in the opposite direction to make up for the lack of rigidity with the grain.

Figure 6.9.
Paperboard is folded away from the score. The bead formed by the female groove in the cutting and creasing press breaks down the bond between the plies of paper. As the sheet is folded, the board delaminates at this point and bulges out into a bead that relieves the stress on the outside layer. Otherwise the outer surface would rupture.

To complete the sample, the outline is cut with scissors or knife, and the scores are made by laying the blank face down on a long piece of scoring rule, which can be obtained from a box supplier. This steel rule is mounted in a block of wood with the rounded edge up. A forked stick is pressed down on the blank and pulled along the pencil lines, directly above the scoring rule. The stick is made from a piece of hardwood with a 1/16-in.-wide and 1/32-in.-deep groove (1.6-by-0.8 mm) in the end. This forms a bead along the score lines that breaks the rigidity of the boxboard at this point and permits it to be folded accurately (see Figure 6.9).

With either method of making the sample, if it is a glued carton the blank is folded, adhesive is applied, and a weight is placed on the carton in the collapsed position until the glue sets. If cutting and scoring have been done carefully, the panels should line up square and true, and tucks and flaps should slide into place with just the right amount of friction. Very seldom is it necessary to trim or rescore for a good fit. This sample can then be used as a check against the dimensions that were originally chosen, to see whether it holds the contents as intended. Typical dimensions are given in Figure 6.10 and correct nomenclature for the parts of a carton are listed in Figure 6.11.

For a carton that must work in automatic machinery, the next step is to have the supplier make a cutting die. At least 500 samples should be made and glued on a production gluer for testing on the cartoning equipment. These do not need to be printed, but should be made of the proper stock.

Today, with the use of a vast and growing variety of software, there is a trend to produce graphics by computer. When used in conjunction with CAD, both carton design and graphics can be merged so that the entire package is created to exact specifications. However, a computer print should not be used as the sample to match in the printing process. The proofing system used for copy and color approval should be the one most compatible with the printing process chosen since printing methods vary greatly.

For smaller manual packagers and printers, if the cartoning-machine test proves satisfactory, a “strike sheet” is prepared. This is an accurate imprint made directly from the ink-coated die on parchment or other nonshrinking material for color and design registration of artwork. The strike sheet should

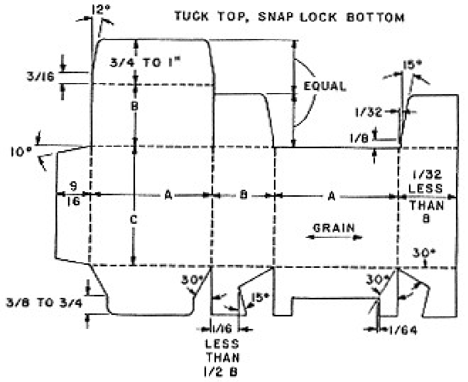

Figure 6.10.
Principal dimensions are shown in a typical carton blank. These are not standardized and there are many variations within the industry.

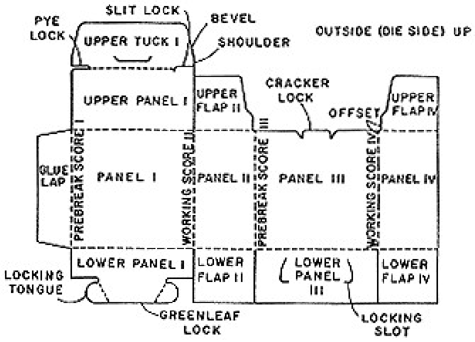

Figure 6.11.
Using proper names for folding carton parts simplifies communication with vendors.

be made from the die and used to prepare the artwork. This die sheet ensures that printing is properly spaced in each panel of the carton.

Carton Manufacture

Cartons are made on cutting and creasing presses ranging in size from Thompson platen presses of less than 30 by 40 in. (76.2 by 101.6 cm) with an output of 1,000 sheets per hour to 72-in. (182.9-cm)-wide Miehle cylinder machines running at 2,400 sheets per hour.

In the carton plant, a cutting and creasing die is prepared for making several cartons at a time. Depending on the size of the item and the quantity required, it may be two- or twenty-up. For purposes of explanation, the cutting and creasing die can be likened to a large cookie cutter. It consists of steel rule set on edge between and projecting 3/16 in. (4.8 mm) above wood blocks cut from plywood, birch, or cherry. This assemblage is held together inside a steel frame or "chase" by wooden wedges or "quoins" (see Figure 6.12).

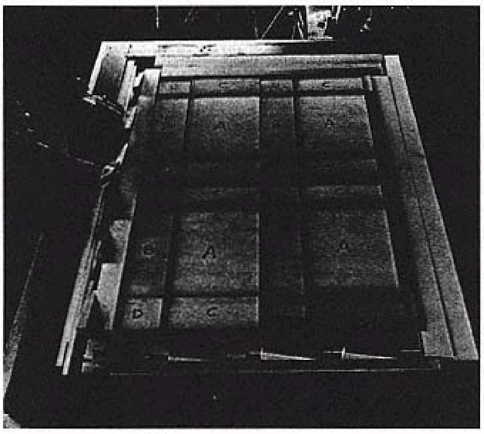

Figure 6.12.
Pieces of cutting and creasing rule are placed between wood blocks inside a chase. Wedge-shaped quoins driven between the furniture lock up the die prior to corking.
(Source: Diemaking Diecutting and Converting).

Small 1/4-in.-thick (6.4 mm) strips of sponge rubber or synthetic "cork" measuring 3/8 wide by 1/2-in. long (9.5 by 12.7 mm) are glued 1/2-in. (12.7 mm) apart on the wooden blocks on each side of the cutting rules, especially where the rules join. This helps the board push free of the knives as soon as it is cut.

Such a die can make up to 500,000 impressions before requiring reknifing. The layout of the die is arranged to get the most economical use of board. Butting and interlocking different positions keep waste to a minimum. If several items are run in combination on the same sheet, the number of positions for each one will be proportional to the order quantities. Sometimes the quantities will be adjusted by "dropping off" the end cartons; that is, a smaller sheet will be used partway through the run so that it does not include the end positions.

From this production die a "rub-off" is made. This enables printing plates in the press to be adjusted in spacial relationship to the die in the scoring and cutting machine.

Today most dies are prepared basically by hand, using a jig saw to cut the wood patterns. Reason is that such jig saws only cost up to $20,000, and the whole operation can be contained in a shed or garage. In fact, many pattern makers have just such facilities and are capable of tolerances as close as ±0.03 in. (0.8 mm).

However, the field of printing and die cutting is growing more sophisticated, with greater quality and precision very much an objective. Enter the laser cutter, which actually burns through the wooden patterns faster and with a precision of up to ±0.002 in. (0.05 mm). However, the cost for laser equipment can run from $75,000 to $300,000 and, currently, is affordable for only the biggest die makers. Without a doubt, however, the trend will continue in this direction.

In preparation for printing, a number of printing plates, or "electros," are made from the original engravings. These are mounted on the printing press to match the cutting die, which has been set up in the cutting and creasing press. Although the sheets will be printed before cutting and creasing, it is necessary to make a temporary setup of the cutting and creasing press first.

Since each row of scores pulls the sheet a small amount, allowance of as much as four 2-point (0.1-mm) "leads" of space must be made for "draw" in the direction around the cylinder. A few blank "set" sheets are run through the cutting and creasing press and put through the printing press to see whether the printing plates are in proper register with the cutting and creasing die, as well as with each other. Adjustments are made, if necessary, until everything is in alignment.

The printing press is then "made ready." That is, the platen is built up wherever the impression is not heavy enough, by pasting bits of paper on the cylinder around which the paperboard is carried when it is being printed, until the impression of the ink on the paperboard is uniform. Solid colors and dark areas of halftones also are built up so that the light areas will not print too heavily. The ink fountains are then adjusted to get an even film of ink on the plates. All this may take from several hours to several days, depending on the complexity of the job. Here, too, there is a move in the printing field to use computer technology that moves graphics straight from the design stage to the press, skipping the preparation of plates all together. The technology is in its infancy right now, but will surely revolutionize the preparation of packaging as well as other forms of printing.

Stock is brought to the press on wood skids with about 1 ton (0.9 metric ton) of board on each. Steel straps and wrappings are removed, and the sheets are then ready to be printed. All the sheets for an entire job are run on the printing press and then allowed to dry for a day or two before being cut and creased.

The cutting and creasing press is made ready in a similar manner, except that the objective is to get the knives to just cut through the paperboard without biting into the steel "jacket" (see Figure 6.13). Pieces of gummed paper pasted on an "overlay" of 0.012-in. (0.30-mm) manila paper placed under the thin steel jacket compensate for any light spots. When this part of the job is completed, a piece of "counter," or "tympan," is glued on top of the jacket. This is a sheet of very dense paperboard slightly thinner than the stock to be used for the cartons. After the glue has dried, the tympan is cut away to form a groove for the creasing rule in the die. Width of this groove should be equal to two thicknesses of carton stock plus the thickness of the rule. For example, if 0.022-in. (0.56-mm) paperboard is being creased with a

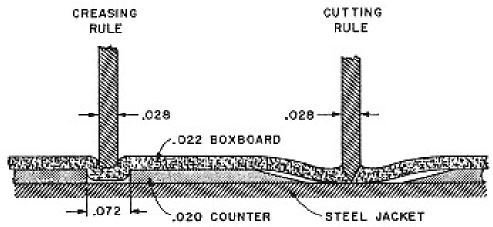

Figure 6.13.
In cutting and creasing boxboard with a steel rule die, the counter is cut away to form a groove for the creasing rule. The counter on each side of the cutting rule is skived away to avoid marking the boxboard. Not shown are cork strips on each side of the cutting rule that strip the stock away after cutting.

28-point (0.7-mm) rule, the groove would be 0.072 in. (1.8 mm) wide. The tympan is also skived away from cutting rules.

The height of the cutting rule is typically 0.937 in. (23.8 mm) across the cylinder and a little less around the cylinder. The creasing rule is a bit shorter, 0.921 in. (23.4 mm). This means that the creasing rule comes even with the top of the tympan, forcing the carton stock into the groove an amount equal to the stock thickness, while the cutting rule goes all the way to the bottom and just kisses the steel jacket. Cut scores are made with a rule of a height that will cut about 75 percent through the board without any tympan in that section. Such partial cut scores assist in bending very dense or thick board structures.

Today on high-speed, large-volume cutting/creasing presses, the carton blanks are separated from the trim waste automatically. However, in small runs and presses, cutting knives are nicked with a very narrow grinding wheel in various places, so that the sheet will hold together after it leaves the cutting and creasing press for hand stripping. In this operation, stacks of cut sheets up to 3 ft (1.4 m) high are stripped by knocking off the trim around the edges and between the cartons with a mallet or, for larger orders, an air hammer. Intricate work or very small cartons may be handled in lifts of only 100 sheets. The stripper first hits the stack in several places to lock the sheets together. Then he pulls on the outside trim while pounding it with his hammer to separate it from the carton blanks.

Carton blanks that are to be glued are then put face down into the magazine of the gluer. A feed wheel slides the blanks off the bottom, one at a time, where they are carried between belts moving at up to 2,000 ft (610 m) per minute into a prebreak station. Here the first and third score lines are prebroken by stationary cams, curved bars that plow up the end panels and then lay them back down again as the blank moves along the belts. Prebreaking can be very important in the subsequent folding and setup of the carton on automatic packaging equipment. See Table 6.6 for how the prebreak angle can affect resistance to bending of carton scores.

Next the glue flap passes over a glue wheel, which is about 3/16 in. (4.8

TABLE 6.6. Effect of Pre-breaking Scores on Bending Resistance.

Prebreak Angle	Bending Resistance (g)
None	360
90	280
135	160
165	130
180	110

Tests made with 0.016-in. (0.4 mm) patent-coated newsback stock on a PCA Score Bend Tester.

mm) wide, and receives a stripe of glue that is thick enough to spread out to the proper width when it is compressed. The belts carry the blank through a folding section where guides or "swords" fold the end panels up on the second and fourth scores and bring them over on top of each other.

Cartons then move into the nip of a pair of wider belts that apply pressure as the cartons are carried along until the glue sets. These wide belts move much more slowly, so that the cartons shingle. When they leave the compression section, they are transferred to a delivery apron and counted. Every fiftieth carton is kicked out of line by a timer mechanism so that the packer can put exact quantities into each shipping case.

A right-angle gluer is slower and more complex. It performs the functions of the straight-line machine, but also is used for more intricate cartons that require folding and gluing of scores that are 90 to the standard lengthwise scores and panels handled in the first type of machine. For some special types of cartons such as diagonal-fold or automatic lock-bottom styles, the glue must be applied in particular spots rather than as a stripe, and the folds must be made with moving arms and special tuckers. The right-angle machine uses lugged timing chains instead of belts to convey the blanks through the first operations. After the blank is glued and folded, it is transferred to a second chain moving at right angles, then transferred to belts. The second gluing and folding operations are similar to the first, but are modified as necessary to suit the style of the carton. Compression, delivery, and counting are much the same as with the straight-line gluer. Ideally, carton overruns for inventory should be maintained in the flat and glued just before shipment to avoid warpage due to inequalities in the thicknesses of glued cartons.

Cartons should be packed in sturdy shipping cases, with about 15 percent extra space to preserve the prebreak. If packed too tightly, the opposite panels will be pressed flat against each other rather than bow out slightly to make it easier to open for filling. Small cartons are best packed in trays, but the contents of large boxes may be simply separated with sheets of paperboard. Cartons must all face one way, especially if they are to be erected by automatic machinery. The shipping cases usually are made of corrugated boxboard and should be strong enough to withstand stacking 5 or 6 ft (1.5 to 1.8 m) high without buckling. Ideally, folded and glued cartons should be inventoried no longer than about six months to avoid warpage and a set to the board.

Carton Filling

A brief description of a typical erecting, filling, and closing operation on a cartoner will show what a user requires in a folding box. There is a great variety of machinery; some very sophisticated, high-speed, and fully automatic in operation; some versatile, semiautomatic, and of moderate capacity. There are machines that fill vertically and others that handle the cartons lying down. There are straight-line and rotary turret or oval-track machines.

Most common is the horizontal cartoner for tuck-end cartons, which we will use for our example. The collapsed cartons are loaded into a magazine, just as the blanks come from the shipping case. Vacuum cups, attached to a swinging or rotary arm, pull cartons off the front or bottom of the stack one at a time and deposit them into pockets of a conveyor chain. At the same time, a pusher bar applies pressure to the trailing, folded carton edge, forcing the leading edge against the front corner of the pocket. The combination of suction cups pulling outward and pressure on the folded edges opens the carton.

As the carton moves along, product is pushed in by hand or from buckets on a barrel-cam auto-loading device traveling alongside the carton conveyor. The dust flaps (the small end flaps) on the leading edge are wiped in by stationary cam bars as the carton moves along, but trailing flaps must be folded forward by revolving fingers that move faster than the carton is traveling. Then the tucks are folded in by stationary, curved cam bars, which bend the score lines and guide the tucks into their slots. Since the cartons move through the machine quite fast (or very fast), design of tucks and flaps must be precise and workmanship uniformly good. If not, the cartons will surely jam.

Printing Methods

Cartons can be printed, embossed, hot-stamped, silk-screened, or decorated with various coatings and attachments. The great majority are simply printed by letterpress, gravure, flexographic or lithographic processes (see Table 6.7). With today's advanced presses, if a good grade of boxboard is used, a high quality of reproduction is possible with 400-line screen halftones and excellent process work.

TABLE 6.7. Comparison of Printing Processes.

Process	Letterpress	Lithography	Gravure	Flexography
Plate costs	Medium	Low	High	Medium
Makeready costs	High	Low	Medium	Low
Solid colors	Excellent	Good	Excellent	Fair
Halftones	Poor	Excellent	Good	Poor
Color control	Good	Good	Excellent	Good
Varnish gloss	Excellent	Fair	Good	Fair

Letterpress gives sharpness and uniformity, offset lithography is recommended for high-quality halftone work, and gravure is preferred for long runs, which are not too complicated. In the past, flexography was used for simple, solid-color designs. However, development of this low-cost process has been very active in recent years and it is now capable of halftone work that, at its best, cannot be distinguished from gravure printing without a magnifying glass.

Lithography has advanced greatly in recent years and probably is the most cost-effective method for producing folding cartons. Make-ready time and plating costs are low. Printing quality can be very good with 150-to 200-line screen art and up to ten colors. Coatings have been developed in high gloss, dull, and combination finishes, which add extra appeal to the art work. Litho presses are available in both sheet-fed and web models and can be combined with rotary cutters that turn out printed carton blanks at the end of the machine.

While big presses still exist, the trend is toward 40-in. (100-cm)-wide units that are more efficient and turn out 15,000 to 20,000 sheets per hour. Make-ready for the color units is from 3 to 5 min, all of which suit user requirements for smaller lots delivered on a just-in-time basis.

Color Standards

If color is important to your package, then its control is essential. When colors are allowed to vary or drift with time, a whole packaging program can suffer. Without proper oversight, colors sometimes can change gradually as a result of simply matching a previous run of cartons or labels. After awhile, the package ends up with a completely different shade or hue from that originally specified. Packages on a store shelf that look faded or are noticeably lighter or darker than those alongside make a poor impression on consumers.

Methods for keeping colors within bounds do not have to be complicated or difficult. The printer can help set up a system of checks and balances to ensure that colors do not vary even as years pass.

Before trying to control color, it is advisable to understand its nature, an infinite variety of hue and chroma. One should also be aware of the difficulty of matching shades under various lighting conditions.

There are several methods of color identification. The Munsell System of Color Notation was developed in 1905 by Albert H. Munsell. Since designers seldom work only in pure primary colors—red, yellow, and blue—but in color mixtures called "hues," the system arranges a color wheel in a horizontal plane around a vertical axis of gray shades with white at the top and black at the bottom. This color tree shows color relationships. Each hue is represented by an initial letter, followed by a superscript number indicating value (the amount of white or black) and a subscript number below a slash mark indicating chroma (the amount of complementary color). Thus, $R^{5}/_{10}$ describes the qualities of vermilion.

A second system adopted in 1931 by the Commission Internationale de l'Eclairage is known as the CIE Color Coordinate System. It works by shining three basic projector lights of red, green, and blue on top of each other on a white screen. If the three lights are of equal intensity, the result is a white beam. If only blue and red are allowed to shine, the result is magenta. Green light plus red light produces a yellow beam.

If the intensity of beams is varied, great numbers of colors can be created. Colorimeters can measure the proportion of red, blue, and green light reflected from a printed sample. The proportions, known as tristimulus values, are expressed mathematically with x = red, y = green, and z = blue. For example, turquoise might have the values $x = 20$, $y = 40$, and $z = 30$. A color diagram can be depicted by plotting tristimulus values on a chromaticity diagram with a vertical axis of gray shades in the middle.

A more recent system, created in 1963 by Lawrence Herbert, is the Pantone System. Pantone, Inc., Carlstadt, New Jersey, produces seventeen different color guides distributed in ninety-five countries. These guides show 1,000 colors, named in six languages and has become the principal color matching system in the printing industry. This color identification employs fourteen basic colors that produce all of the various hues and values in the system. All colors are given a number. For example, 297 is a light blue and 300 is a darker blue.

There are numerous other methods devised to classify colors. Among these are the Oswald system, published by Container Corp. of America (now part of Packaging Corp. of America, Evanston, Illinois); the Swiss Color Atlas, which follows the general order of the Oswald system; Villalobas, printed in Buenos Aires; and the *Dictionary of Color,* published by the McGraw-Hill Book Co., New York. In addition, many suppliers publish color cards in a full spectrum of hues and values.

Color Control

The principal components of color are brightness, hue, and saturation (chroma). The effect on the observer is the total of all these variables, influenced to a greater or lesser degree by personal bias and the particular circumstances in each case. Response of the eye to color stimuli is greatly influenced by the characteristics of the reflective surface. A varnish overcoat deepens colors, especially darker values of certain colors. The quality of the substrate and the thickness of the ink film also contribute to differences.

Thus, specification of color by formula numbers alone is not sufficient since the manner in which inks are used greatly influences the final result. Transparent inks are particularly difficult to specify. In some plastics, the thickness of the translucent material has a direct bearing on chroma. Certain plastics have a distinct yellow tint that influences the total color blend. While this factor is not too troublesome in warm tones, it can cause difficulties with blues and purples.

For a single cosmetic package, there may be such dissimilar materials as a satin ribbon, a lamb's wool powder puff, a plastic box, paper label, and paperboard carton. Even though these materials may have very different textures, specifications may demand that they be the same color. This requires that each item be matched against a single set of standards, which is generally printed on boxboard.

Comparisons should be viewed at arm's length under various lighting conditions: indirect sunlight, incandescent light, and fluorescent light. Although this requires judgement, it is within the capability of an average, trained inspector. For such complex packages, a separate set of light and dark limits for each material is impractical. To establish and maintain such an elaborate set of standards would require a great amount of time, and few companies are so well staffed that they can go this far in color control.

While there may be good reason for the use of sophisticated instruments in color evaluation, practical packaging color control requires a simpler, less expensive, and more flexible method that can be understood by people in purchasing, production, and inspection. The usual procedure employs standard swatches or chips of the desired colors that can be sent by mail, carried into press rooms, and used on the inspection table.

There are four major steps to this system: (1) Start with a color sample that is acceptable to both vendor and packager. Work with one of the color systems. Pantone is a good one because it uses a separate number for every color, whereas names of colors can vary from one supplier to another. (2) Have the vendor make up samples in the material to be used. Coated boxboard is generally suitable. (3) Work out tolerances acceptable to both vendor and packager. (4) Provide duplicate sets of color swatches to both vendor and to packager inspectors of incoming materials.

A folding carton supplier will usually cooperate in making up standard swatches. First samples may be in the form of press proofs, which usually provide the best results since all colors are viewed together. A color often appears differently when it is placed next to another color and, since the main interest lies in the final effect, it is best to see the colors in their proper relationship.

However, “wipe-downs” of each solid color may be more suitable. This sample is made with a metal straight edge that has a high spot at either end, permitting a thin layer of ink of uniform thickness to remain on a flat board surface when drawn across a pool of ink on the board. Solid-color samples also can be prepared on a proof press. The samples should be dried for at least 48 hours, including a varnish overcoat if one is planned.

A convenient method of preparing tolerance standards is to have them printed by the supplier on heavy paper or boxboard. The ink supplier and ink formula number should be included for reference. It is also a good idea to have both varnished and unvarnished samples mounted in a three-page fold-out (8-1/2 by 11 in., 216 by 279 mm) that can be stored in conventional file drawers with the light-color limit swatches stapled on the left panel, the standard swatches in the center and the dark-limit swatches on the right.

These should be solid blocks of color with one half varnish coated. All colors for a single package should be filed in a single folder. Several copies are kept on file to provide to different vendors. The color swatches should be covered with black paper free from sulfur or other contaminants that might create a chemical reaction with the inks. They should be stored in the dark and only exposed to light for brief periods as necessary. However, color standards will deteriorate with time and should be replaced periodically. Since some colors age faster than others, standards should ideally be replaced once a year.

While special shadowless inspection "boxes" are used as standard light sources, the first sample inspections should be made under the three lighting conditions mentioned before. After samples have been approved, they should be signed and dated. One sample is returned to the vendor, the others are filed by the packager, as described above.

There should be an understanding with the supplier that any deviation from this first color standard must be kept within commercial limits. While such a term is ambiguous, it usually means that variation is kept within the capabilities of the system; for example, one notch in either direction on the ink-fountain adjusting screw. After a first press run, light and dark limits can be established with appropriate swatches.

If more exacting color control is desired, there are instruments that overcome the limitations of visual measurement. For example, one such device is a spectrophotometer designed in 1935 at the Massachusetts Institute of Technology, Cambridge, Massachusetts, by Dr. A. C. Hardy and produced commercially by General Electric (now GE Co., Fairfield, Connecticut). It measures the percentage of light reflected at each wavelength of the visible spectrum from 400 to 700 m (4 10^7 to 7 10^7 Å). By drawing a continuous curve of these readings, an accurate color record is produced. A tristimulus integrator can be attached to the instrument to provide the three tristimulus values, *x, y,* and *z*.

Set-up Boxes

A set-up box is similar in some ways to the folding carton described on the previous pages, but there are major differences both in methods of manufacture and usuage. By definition, it is made in its finished shape; it cannot be collapsed for shipment. The manufacturing plants for set-up boxes tend to be smaller and less sophisticated than folding-carton plants. But like folding cartons, set-up boxes are quite versatile. Set-up boxes consumed about 332,000 tons (301, 390 metric tons) of paperboard in 1995 [3].

The processes for making set-up boxes do not require expensive dies or complicated machinery. Thus, small runs and unusual constructions are easily accommodated. Costs are considerably higher than for folding cartons of equal size. However, there are some extra benefits in rigidity and appearance, which cannot be matched by the folding carton. For these reasons the set-up box is most often used for luxury goods (see Table 6.8).

Set-up Box Construction

Paperboard of the nonbending variety forms the base of the set-up box. This runs from 0.016 to 0.062 in. (0.41 to 1.58 mm) in caliper or, as it is sometimes designated, from No. 35 to No. 120 board (the number of sheets in a 50-lb. bundle). Most uses are in the 0.040- to 0.050-in. (1.02- to 1.27-mm) range. The board is frequently lined or laminated with white paper on the inside surface. The corners are usually reinforced with 30-lb (13.6-kg) gummed paper tape, known as “stay paper.”

The outer surface is typically covered with a 60-lb (27.2-kg) coated litho paper, which has been preprinted or decorated. Other types of cover paper may be used, and there is an endless variety of foils, embossed or flocked papers, and fabrics available to the box designer.

The simplest style is the telescope in which the lid is slightly larger than the base and fits down over it, either partly or to full depth. Other variations include an extension edge on the bottom or a hinge on the cover and

TABLE 6.8. Uses of Set-up Boxes

Use	Percentage
Candy	16
Stationery	15
Pharmaceuticals	13
Department Stores	9
Jewelry	8
Wearing Apparel	5
Food	5
Photographic Products	4
Cosmetics	4
Hardware	3
Miscellaneous	18

padding on the top surface. There is almost no limit to the variety of drawers, trays, and platforms that can be included for special purposes. A few basic styles are shown in Figure 6.14.

Set-up Box Design

Cover papers are usually printed in the flat, and then wrapped around the box. Any graphic process may be used for the printing, such as letterpress, offset, hot stamping, embossing, or silk-screen. Attachments can be added in the form of hinges, latches, medallions, ribbons, or cords to make the package more attractive as well as functional. The processes that are used in making set-up boxes lend themselves to such innovations, and the designer has ample opportunity for developing unique and interesting creations.

In working out the design for a set-up box, there are several things to keep in mind. A printed border is not recommended, as it is difficult to keep parallel with the edge of the box and to maintain an equal distance all around. For the same reason, a line or color separation should not occur right at the edge. Horizontal lines running around the four sides will seldom meet exactly at the corners. It is best to get a layout sheet from the box maker before making the final black-and-white pasteup, to be sure the spacing is right.

Bleed should be carried to about 1/8 in. (3.2 mm) beyond the trim line and at least 1/4 in. (6.4 mm) where the turn-in goes inside the cover or base. Offset printing should be specified for most purposes, but letterpress also can be used.

The first step in manufacturing set-up boxes is to score the blanks for the lid and base. A sheet of boxboard about 24 by 36 in. (61 by 91 cm) is put through a scoring machine, then turned and put through another similar machine for scoring in the opposite direction. The scores are made halfway through the board, but the outside edges are cut completely through, and several lids are usually cut at the same time from one sheet.

A stack of lids or bases is then put into a corner cutter, where one corner of the stack is notched out at a time. The stack is turned and returned to the machine to notch each subsequent corner. Single blanks are then stayed in another machine, which bends up the flanges on the score line and puts a small strip of gummed stay paper around the corner to hold them in place. Figure 6.15 shows how the various parts go together.

The cover paper may be made in several pieces and applied to the box in separate operations. For example, the sides could be covered by a strip running all the way around, like the stripped neck in Figure 6.15. This would extend for a short distance onto the top, if this were a lid. A label would then be glued over the top; it would run just to the corners of the lid, covering the edges where the side strip extends onto the top. An alternate method is to cover the top and sides of the lid and/or base with a one-piece wrapper, as shown in Figure 6.15.

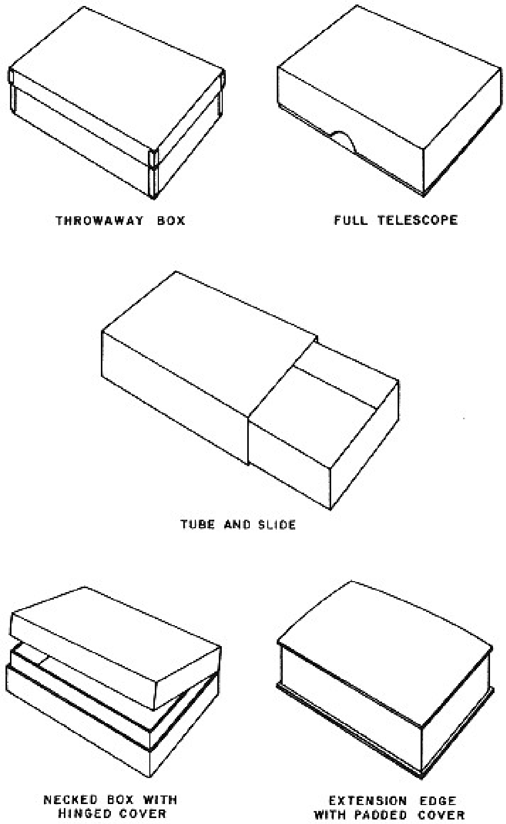

Figure 6.14.
Set-up boxes have many variations including these basic types.

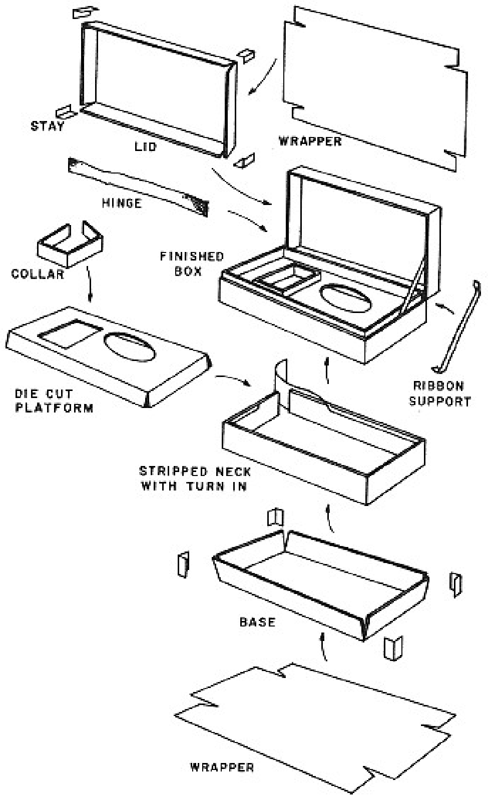

Figure 6.15.
Construction of a set-up box shows how various parts are assembled into a finished package.

Much of this is handwork, but automation is possible if volume is sufficient to justify the cost of tooling. Hinged cigarette boxes for premium brands, for example, are made on high-speed, completely automatic machines.

Set-up box costs are not influenced as much by quantity as some other package forms. In small quantities, costs are somewhat higher, but compare very favorably with folding cartons because of the high makeready costs for folding cartons. As the volume goes up, the cost of the set-up box goes down only a small amount, whereas the folding carton becomes significantly less expensive.

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Chapter 7— Fibre Tubes, Cans, and Drums

Introduction

Almost as versatile as folding cartons are the canisters created from paperboard that are also frequently combined with metals, plastics, films, coatings, and adhesives. As with all other packages, the basic principle in working with this composite structure is to combine materials that are best suited for the purpose and in the minimum amounts necessary to accomplish the packaging objectives.

The expensive materials can be minimized by using thin layers, supported by inexpensive paperboard for strength and rigidity. Fragile components of a lamination can be buried between other more sturdy materials for protection. In this way it is possible to produce containers that will do things that no single material could accomplish.

As a result, the "fibre can" has found its way into the packaging of a host of food, beverage, and nonfood products (see Table 7.1). The canister is also now being considered for paints. Another significant part of the business, fibre tubes with nozzles and plungers, are used for adhesives and sealants.

History

Paper tubes were first used during the Civil War for ammunition. These containers had paper bodies and ends. By the end of the nineteenth century they also were being used for dynamite. More peaceful packaging applications for relatively stable products followed into the twentieth century.

Higher barrier applications evolved in the early 1950s in the form of ready-to-bake biscuit dough in a foil-lined composite can developed by Bill Fienup of R.C. Can Co. in St. Louis (now part of Sonoco Products Co.,

TABLE 7.1. Typical Uses of Fibre Cans.

Salt
Cereal
Frozen Fruit
Grated Cheese
Frozen Juice Concentrate
Refrigerated Dough
Spices
Nuts
Coffee
Cocoa
Powdered Beverage Mixes
Snack Food e.g., Chips, Crackers
Shortening/Edible Oil
Pet Food
Tobacco
Talc Powders
Household Chemicals
Garden Supplies
Petroleum Products

Hartsville, South Carolina). This usage expanded later to include sweet rolls and other refrigerated dough products. The spiral-wound can is particularly well suited for this purpose, and the genius that developed this package-product concept is one of the unsung heroes of the packaging profession.

The combination of high-test paper to withstand the pressure of the rising dough and foil to retain the shortening and water without label staining is very effective and met with instant success. Housewives were fascinated with the convenience of opening the can by rapping it against the edge of the table, and popping the biscuits into the oven without further preparation.

Partly as a result of the methods and equipment developed to produce the above packages, composite cans for citrus concentrates and lubricating oil were introduced in the late 1950s. About 85 percent of citrus concentrate containers or about 2.5 billion cans, are now used for these products. Success in replacing metal cans led to adoption of fibre cans for motor oils, a giant market that has now diminished as petroleum packagers have switched to more shapely plastic bottles with convenient long necks for easy pouring (see Chapter 8, Plastics).

The capability of achieving a true double-seam closure on these cans has prevented leakage. A wicking problem under the foil liner where a paper edge was exposed at the overlap has been cured by folding the foil and paper lamination back on itself, so that no paper is exposed. This is sometimes called an Anaconda fold. These improvements have given the fibre can a barrier capability that has led to its use with nitrogen flushing for products such as nuts, snack foods, and powdered mixes and may soon result in equal use for vacuum packaging. Today, 75 to 100 plants make about 7.5 billion composite cans each year valued at more than $400 million.

Forms and Modifations

There are three major types of bodies for composite cans: convolute, spiral-wound, and linear draw. There is also a lap-seam style that is really a convolute winding of a heavy and often laminated material that is stopped at the end of the first winding (see Figure 7.1). In all instances, the bodies are wound on a mandrel and trimmed to length. Spiral winding can form only cylindrical shapes, whereas convolute and linear-draw methods also can produce squares, oblongs, and ovals.

In convolute winding, the various layers are carried over glue rollers and then fed straight onto a revolving mandrel (see Figure 7.2). After three to five revolutions of the mandrel, the stock is cut off and wiped down. An outer label may be applied, after which the tube is cut to length and one end is attached.

Spiral winding, the most popular and cheapest method, is faster, makes better use of materials, and is a more economical process. With spiral winding, the material is carried over glue rollers, fed at an angle to a stationary mandrel, and carried around it by a moving belt to form a continuous tube (see Figure 7.3). The tube is cut to length as it comes off the end of the mandrel and the bottoms are added later in a separate operation.

The newest method, linear draw, was commercialized in 1996. It involves bringing four plies of material together in a horizontal plane and folding them up and around a mandrel (see Figure 7.4). This enables production of containers with varying barrier properties and nonround shapes. Its other

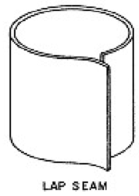

Figure 7.1.
Lap-seam bodies are made from laminated material, cut into blanks and joined at the side with adhesive.

TABLE 7.2. Standard Sizes of Fibre Cans

	Diameter										
Height	112	185	198	200	201	202	204	208	211	213	214
110				X							
200											
208		X									
209									X		
211							X				
212				X							
215							X				
301							X				
304									X		
306			X				X				
308									X		
309											X
310	X								X		
313									X		
314						X			X		
400							X		X		
405							X		X		
408							X		X		X
412		X									
414									X		
500									X		
502							X				
504			X	X			X		X		
506							X				
508									X		
509							X				X
512										X	
514							X				

(table continued on next page)

Table 7.2. (continued)

	Diameter										
Height	112	185	198	200	201	202	204	208	211	213	214
601										X	
602									X		
604							X		X		
606									X		
608							X				
609								X	X		
610										X	
700	X										
704			X	X			X				
712										X	
800								X	X		
812										X	
904					X	X					
972								X			
1000	X										

	Diameter							
Height	300	302	304	307	401	502	503	610
200	X							
210			X	X	X			
212					X			
213				X				
300					X			
301					X			
303					X			
305					X			
308					X			
310	X				X	X		
311					X			
312					X			
400					X			

(continued)

(table continued on next page)

TABLE 7.2. (continued).

	Diameter							
Height	300	302	304	307	401	502	603	610
401					X			
403					X			
404				X	X			
405					X			
406					X			
407	X							
408					X	X		
411					X			
412						X		
413						X		
414						X		
415				X		X		
500					X	X		
502					X		X	
503	X							
504	X				X	X		
505					X			
506						X		
508						X		
509	X				X			
510					X		X	
512						X		
514					X			
600					X	X		
602					X	X		
603					X			
604					X	X		

(table continued on next page)

Table 7.2. (continued).

	Diameter							
Height	300	302	304	307	401	502	603	610
606					X	X		
608				X	X	X		
609	X				X	X		
610						X		
611	X	X						
612					X			
613		X				X		
615				X				
700				X	X	X	X	
702	X							
704						X		
705						X		
708						X		
712						X		
715					X	X		
800	X				X	X	X	
805					X			
806					X			
807					X			
808						X		
812							X	
815				X		X		
900					X			
901					X			
904						X		
908						X		X
909	X							
910						X		
912					X			
1204							X	

Note: The first digit of each dimension designates whole inches, and the second and third digits designate sixteenths of an inch. Thus, 211 equals 2-11/16 inch.

Source: Sonoco Products Co., Hartsville South Carolina.

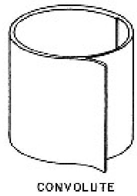

Figure 7.2.
Convolute winding coils several layers on top of each other, straight in from the side.

point of differentiation is the base, a paper/foil laminate, which is heat-sealed in place.

Fibre tubes are made in a vast number of configurations and sizes from 0.41 in. to 5 ft (10.4 mm to 1.52 m) in diameter and 0.25 in. (6.4 mm) long to any length that can be conveniently handled. For cans, the range of diameters is usually between 1 and 7 in. (2.5 and 17.8 cm) with heights from 1 to 13 in. (2.5 to 33.0 cm). There also are some standard sizes (see Table 7.2). The dimensioning protocol is the same as for metal cans where diameter and height are designated by three-digit numbers designating whole inches and 1/16th fractions of an inch. Thus, a 204 514 canister measures 2 4/16 in. (5.7 cm) in diameter by 5 14/16 in. (14.8 cm) high.

Today, almost any desired amount of rigidity can be manufactured in a composite can by varying the thickness of the paperboard walls. In a similar manner, oxygen and moisture barrier can be incorporated economically by using a liner of barrier plastic resin, metallized film, or coated aluminum foil in various coextruded or laminated structures.

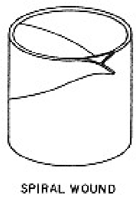

Figure 7.3.
Spiral winding usually consists of several layers of different materials with angled overlapping joints. Resulting containers are always round.

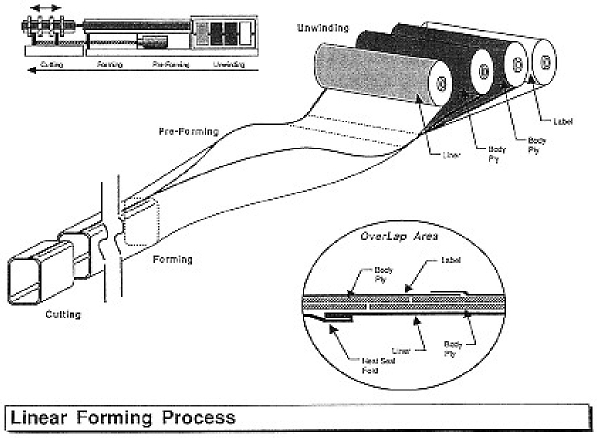

Figure 7.4.
In the linear-draw process, plies of material including an outer label ply are fed in a horizontal fashion, drawn up and around a mandrel and sealed to form a tube, which is then cut to size.
(Source: Sonoco Products Co., Hartsville, South Carolina, used with permission.)

Easy-opening and functional features such as pour spouts may be included. From the beginning, suppliers have devoted considerable developmental effort to address openability. Early on Sonoco patented a "coining" process to groove metal ends to make them more can-opener friendly. Another familiar opening device is the mirastrip for frozen concentrate cans. A unique opening feature developed for refrigerated dough packages offers designed vulnerability, the spiral overwrap is constructed to fail and split when the container is struck against a hard surface. More recently, easyopen ring-pull aluminum ends and tabbed membrane seals, which adhere to metal rims or the beaded top of the can itself, have been developed.

Shoulders can be created by placing an extra tight-fitting tube inside the body and projecting it above the top edge, which enables a telescoping cover of the same diameter as the body to be fitted over the end. Fireplace matches are sometimes packed in this type of container.

Sifter tops, used with certain types of products, are readily available in either plastic or metal; in all, making this container very versatile for many applications.

Advantages and Disadvantages

There are two significant weaknesses in composite containers, however. The joining of the end closures with the sidewalls can be difficult. When the metal is curled over so that it grips the body tightly around the rim, the metal bites into the soft paperboard and the ends may separate from the bodies in shipment. This may occur when the bottom edge of one can overrides the rim of an adjacent can and forces the closure downward from the body. The other hazard in shipping is a side shock which presses the rim of one can against the body of another one, tearing the paperboard inward from the rim. Similar damage occurs if metal cans are not properly packed for shipment.

Another point to keep in mind is the vulnerability of the overlap. It is difficult to get a secure joint, and wicking may take place where the edges are exposed to liquids or pastes. "Skiving" (cutting away or tapering) the edges will minimize this condition, but requires close control in the manufacturing operation. On cans above 401 in diameter, the greater thickness of the rim can make it difficult to operate some can openers. A fibre body is three times thicker than a metal body, and when the ends are double-seamed, the extra thickness will not fit between the cutting and the driving wheels on the can opener. However, with the growing number of easy-open designs, the use of can-opener ends is declining.

In comparison with metal containers, a fibre can provides far more thermal insulation, which may be good or bad, depending on the type of product it contains. If quick freezing is part of the process, the fibreboard will interfere with rapid cooling. On the other hand, it can protect products from a temperature change, which might be detrimental.

Materials and Processes

Paperboard containing primarily recycled fibre is the basic material from which canister bodies are made, although adhesive and extrusion laminations of paperboard with plastic films or metal foils are increasingly common. For maximum strength, unbleached kraft paperboard is the best choice. By using this material, it is possible to get stacking and side compression strength equal to that of an all-metal can at up to 25 percent less cost. Wetstrength resins and various binders can be included in the furnish used for making the paper to provide special characteristics, which may be needed in the final package.

Outer plies, often printed or coated to improve their visual qualities, usually are selected on the basis of appearance. Where cost is important, chipboard is used. But, more often, other factors are involved, and it becomes a case of balancing strength, porosity, glue holdout, and shrinkage against the base cost of the paperboard. Inner plies can be tailored to provide barriers. Aluminum foil, the maximum barrier, is especially effective against moisture and greases, but, today, many films can offer these properties at a lower cost. Where a specific requirement can be met with glassine paper, plastic film, or a wax coating, the economics will usually dictate the choice of these materials (see Chapter 2, Paper and Paperboard; Chapter 3, Films and Foils; and Chapter 4, Coatings and Laminations).

Various adhesives, primarily water-based, are used including ones developed to meet particular needs. Silicate adhesives are low in cost, have good tack, and are stiff when dry. They also are odorless and vermin proof, and add more stiffness to the tube than most other alternatives. Dextrin adhesives are quite inexpensive and also widely used. They do not dry very quickly and have poor water resistance, but are satisfactory for many purposes. Other commonly used adhesives include polyvinyl alcohol-acetate blends, polyethylene, and hot melts. Starch pastes, jelly gums, and other heavy-bodied adhesives are not fluid enough for tube winding (see Chapter 13, Caps and Seals).

Top and bottom end closures can be made from paperboard, plastic, or metal and do not necessarily have to be the same material. Plastic closures are injection molded from a variety of resins and metal ends are made from tinplate approximately 0.0105 in. (0.27 mm) thick or aluminum up to 0.0145 in. (0.37 mm) thick. The choice depends on cost and usage. For example, household can openers require the hardness and magnetic properties of steel for easy opening. Tinplate or tin-free steel also is used for friction plugs, pour spouts, sifter tops, and other convenience features. But aluminum can be more economical and is lightweight, rustproof, and low in tensile strength, an advantage if a tear-open feature is needed.

A more recent development, peelable membrane closures, provide both tamper evidence and a hermetic seal. Together with improvements in sidewall barriers, as discussed above, this closure innovation is enabling use of nitrogen-purge and vacuum packaging of fragile foods such as nuts and powdered milk, respectively. A valved version that releases carbon dioxide allows freshly roasted coffee to be ground and packaged without the usual standing time for off-gassing. (More information on metal can ends can be found in Chapter 10, Metal Containers.)

In the spiral-winding process, paperboard is slit into narrow widths and wound into rolls 3 or 4 ft (0.91 to 1.22 m) in diameter. Width of the roll is related to the diameter of the finished tube; it is normally between one-and-a-half and two times the inside diameter. The outer ply is often a labelstock with angled graphics, so that when it wraps around the tube, the printing becomes straight and matches where the edges butt.

The rolls of paperboard are mounted on “unwind stands” on both sides of the tube machine. A means is provided for splicing in a new roll as the old one runs out without interrupting the operation. The edges are sometimes skived just before the adhesive is applied for a better and slightly overlapping fit. The paperboard is threaded down into a glue pot, where it is coated on both sides with adhesive. The excess is doctored off by bars with notches about 3/16 in. apart, so that stripes of glue remain. The spacing and depth of the notches are such that the glue will spread into a solid film when it is pressed against the next layer of paperboard. Sometimes only one side of each ply is wet with glue and is roll coated.

After being coated with adhesive, the ribbons of paperboard travel at an angle onto the top of the mandrel and around it in an overlapping helix. A belt goes on top of the paperboard and makes one turn around the mandrel on the outside of the paperboard tube, following the corkscrew direction of the paperboard ribbon and providing the driving force to keep the tube spiraling off the end of the mandrel.

The mandrel does not revolve, but remains fixed. A drive belt is supported on two vertical pulleys, mounted on each side of the mandrel; the belt goes around the mandrel, then makes a half twist and wraps around one pulley, goes straight across the mandrel to the opposite pulley, and after going halfway around it, finally returns to the mandrel again in an endless circuit. The pulleys and belt make up the main part of the winding head, and the angle that it makes with the axis of the mandrel can be adjusted to suit the width of material and the diameter of the mandrel.

The diameter of the polished steel mandrel determines the inside dimension of the finished tube. These tools are interchangeable and can be made in any desired size, so that close fits of telescoping parts can be accomplished by changing mandrels until a precise fit is achieved. One end of the mandrel is fastened solidly to the machine, but the takeoff end is unsupported. The distance to the cutoff point is determined by several things, but mostly by the amount of time it takes for the glue to setup.

A circular knife or a revolving saw cuts the tubing to length. The most widely used cutoff, a freely spinning circular knife, presses against the tube as it moves along the mandrel and is backed up on the opposite side by supporting rollers. The knife travels along with the tube until the cut is completed and the piece drops off the end of the mandrel. Then the knife pulls away and returns to the starting point. Heavy-wall tubes are cut with a revolving saw instead of a knife.

In some high-production operations, cut tubes are fed directly into the next operation such as recutting or flanging. Not all container bodies are recut, but very short bodies or neck sections that cannot be cut quickly enough on the regular automatic cut-off section must be taken off in longer lengths and recut into smaller units.

Sometimes bodies are flanged before the ends are applied to get a more secure seal. Otherwise a burr, formed on the inside edge by the cutoff knife, might reduce the inside diameter and make positioning the ends more difficult.

The number of plies in the body can vary from one to a dozen or more. The more plies for a given wall thickness, the greater the strength of the tube, as a general rule. However, the cost increases with the number of plies, owing to the added material costs. The maximum thickness of any ply is limited by the ability of the material to bend around the canister diameter without cracking and with a minimum of springback. Most citrus concentrate cans are now being made of only one ply of material by skiving the edges so that there is no extra thickness at the overlap. This permits faster freezing. Resistance to side pressure is not as good with skived joints, but resistance to end pressure is better than with overlapped or staggered joints.

The liner and label material for a composite container may be prelaminated to the paperboard if they are too light or stretchy to be handled separately on the winding machine. The adhesives used for this and other operations will depend on the specific needs in each case.

If the adhesive is applied on the winding machine, it can be put on one or both sides. For two-side application the paperboard is carried through an immersion tank, where it travels under one or more bars.

In the case of one-side coating, rollers apply adhesive against the underside of the paperboard as the ribbon of material passes over the top of the rollers. Another technique is to bring half of the plies in from one side of the machine without adhesive, and half from the other side with glue on both sides. This method uses less adhesive and minimizes shrinkage, but is more difficult to set up.

Another development in the creation of composite containers is the inplant manufacture of single-wrap convolute cans. Capable of speeds up to 200 6-oz containers per minute, the machine folds or wraps a heat-seal-coated paperboard or paperboard laminate blank around a mandrel to form a straight-or tapered-wall container. Typically used for dried fruit, oatmeal, cereals, grains, and ice cream, the containers can be round, oval, or rectangular with rounded corners (see Figure 7.5). End styles include crimped-on aluminum; friction-fit plastic; and paperboard, either knurled, heat-sealed, and inset in place, or, more recently, sonic-welded flush bottoms. Lids can be flexible membranes with or without plastic overcaps or friction-fit paperboard.

Advantages include just-in-time production, reduction in inventory and shipping, high shelf impact with flexo or litho printing in up to six colors,

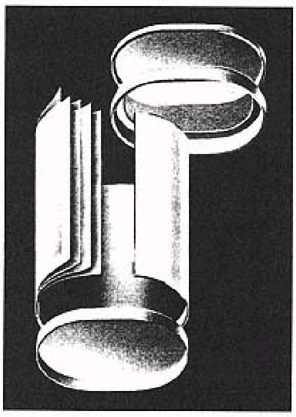

Figure 7.5.
Single-wrap convolute or side-seam containers are made in-plant from preprinted flat blanks. Rounds, ovals, and oblongs can be formed, using various laminations of paper, plastic, and foil.
(Source: International Paper Co., Purchase, New York, used with permission.)

stackability, and durability. In addition, the container-forming machine measures roughly 6 by 6 by 4 ft (1.83 by 1.83 by 1.22 m), significantly smaller than a spiral-wound tube line. The in-plant-produced containers offer some savings potential due to reduced storage requirements and shipping costs because incoming materials are more compact and finished packages are lighter than other alternatives.

While convolute cans are wound straightaway, in all other aspects they are similar in principle to spiral-wound cans. However, the convolute design offers greater strength. The lap seam is simply a single turn with an overlap of prelaminated materials. A good example is in-house-produced containers and citrus juice cans.

In the linear-draw process four plies of material including an outer label ply are brought together and fed horizontally to a forming area where the outer edges are drawn up and around a mandrel and sealed to form a tube which is then cut to size (see Figure 7.4). A second machine forms and heat-seals paper laminate bottoms and beads the top edge of the canister.

Fibre Drums

A larger version of the fibre can, the fibre drum, is used for shipping bulk chemicals and other industrial products. Fibre drums are used for a variety of nonhazardous and mildly hazardous dry and liquid products including chemicals, foods, pharmaceuticals, paints, and adhesives. A wide range of standard sizes is available from stock with end covers of metal, plastic, or fibreboard, and body constructions that include a variety of laminations and coatings (see Table 7.3) [1].

Fibre drums are lightweight and have exceptional strength in proportion to their weight. Although essentially a single-trip container, fibre drums sometimes are reconditioned and used for several trips. The railroads frown upon this practice, but will allow step-down reuse; that is, liquid containers can be reused for paste, and paste containers for dry products.

History

The earliest known commercial use of fibre drums was in 1904, when a cheese manufacturer replaced its wooden drums with all-fibre containers. Since then the U.S. industry has grown to about 50 fibre drum plants and an annual production of nearly 35 million containers worth about $350 million. With 30 percent of the industrial container market, fibre drums fall in the middle between steel at 60 percent and plastic at 10 percent.

Advantages and Disadvantages

The light weight of these paperboard containers helps reduce tare weight and, consequently, shipping cost, for many commodities. On average, fibre drums are 50 percent lighter than a steel drum of equivalent size. For powders and granular materials, the fibre drum is the most economical bulk rigid shipping container.

Fibre drums have a high strength-to-weight ratio if stacked upright, but should not be stored on their sides, as strength in that direction is rather

TABLE 7.3. Standard Capacities of Fibre Drums (gal).

5	20	35	50	65
10	25	40	55	70
15	30	45	60	75

Source: International Fibre Drum Institute, Washington, D.C.

poor. These drums are easy to open and reclose, and provide excellent protection for their contents. However, even with a waterproof treatment on the outside, the containers generally are not designed for outdoor storage and should not be exposed to the weather for any length of time. Disposal is no problem, since they can be incinerated easily.

While interchangeable with metal drums for some products, fibre drums cannot compare in strength with a heavy-gauge steel drum.

Fibre drums have been used for 30 years to package certain mildly corrosive and flammable liquids. However, recent changes in U.S. Department of Transportation regulations, if unchanged, would eliminate the use of fibre drums for any hazardous liquids. Fibre drums intended for use with liquids must withstand drop and tip-over tests without leaking, according to Item 296 of the *National Motor Freight Classification* (trucks) and Rule 51 of the *Uniform Freight Classification* (railroads), available from the American Trucking Associations, Alexandria, Virginia, and the National Railroad Freight Committee, Atlanta, respectively [2, 3]. Restrictions should be studied carefully before adopting this form of packaging.

A special type of drum for hot-poured materials consists of a lap-seam body with a "free stripping" coating on the inside. Most often used in 13- and 55-gal. (49.2- and 208.2-L) sizes for roofing compound, waxes, rosins, or similar materials, which are solid at ambient temperatures, this design is easier to open, with less risk of personal injury, than metal containers, and disposed of easily by burning.

Materials and Types

Fibre drums are either cylindrical or square in cross section and described according to capacity; nominal internal and outside diameter; and internal, external, stacking, and overall height (see Figure 7.6) [4].

The tops and bottoms are either 24- to 30-gauge (0.025- to 0.013-in., 0.64- to 0.32-mm) steel or 0.090- to 0.240-in. (2.3- to 6.1-mm) waterproof fibre-board. Tops also can be made of high-density polyethylene or polypropylene ranging from 0.060 to 0.125 in. (1.5 to 3.2 mm) thick and with concentric reinforcing rings. Specifications are given in the *Uniform Freight Classification* [5] and *National Motor Freight Classification* [6].

The bodies are convolutely wound of several plies of 0.012 to 0.016-in. (308- to 410-   m) fibreboard formed into a tube by gluing with a silicate adhesive or laminating. To impart required properties, special inner and outer plies can be specified; inner and outer surfaces can be coated with wax, polyethylene, or other material; and inner barrier plies such as asphalt, polyethylene, polyester, polyvinylidene chloride, polyvinyl acetate, and/or foil can be part of the structure. If preferred, the barrier layer can be laminated to the

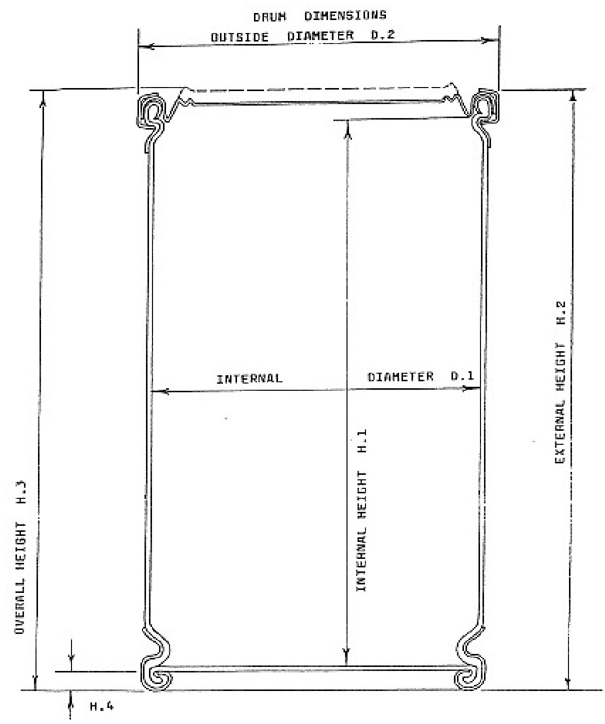

Figure 7.6.
Drum dimensions should be described as shown in this illustration of a typical design. Capacity is calculated using dimensions D1 and H1; while shipping cube is figured using dimensions D2 and H2.
(Source: International Fibre Drum Institute, Washington,

outer or inner sidewall. For oils and greases, the barrier layer should be inside next to the product.

The total thickness must be 0.0625 to 0.2125 in. (1.59 to 5.40 mm), as specified in the various carrier regulations. Sidewall strength requirements are described in the regulations in Mullen test units, which are roughly equivalent to the bursting strength in pounds per square inch. The range is from a Mullen test of 400 psi (2,758 kPa) in the smaller sizes, up to a 1,200-psi (8,274-kPa) sidewall for the largest heavy-duty drums. It should be noted that the Mullen test value of a laminated structure is somewhat higher than the test value of an individual ply multiplied by the number of plies. Code numbers for the different drum sizes and types are assigned by the manufacturers and provide information such as diameter and gallon capacity.

The most popular style of end for small-size drums, fibreboard, forms a flush joint via a deep edge that telescopes down over a neck piece, which is slightly smaller in diameter than the body. This is sealed with gummed or pressure-sensitive tape. Two plies of 3-in.-wide, 60-lb (7.6-cm, 27.2-kg) kraft tape are recommended.

In the larger sizes there seems to be a preference for metal ends. Steel covers are secured either by a locking ring with a toggle to draw it up tight (Figure 7.7) or with several lugs around the edge. A sponge rubber gasket or other similar material provides a hermetic seal when the locking ring is drawn tight. With the reinforcing band, the locking ring, and the cover, there are three layers of steel around the top edge to resist the hazards of shipping and warehousing.

Figure 7.7.
A popular style of closure for drums is a lever-actuated band that draws the cover down tightly against the metal rim of the drum. A gasket in the cover provides a hermetic seal. The toggle action of the lever makes it easy to close, and a pilferproof wire seal can be used for security. A metal tool is available on request from the drum manufacturer to facilitate opening the latch and lifting the cover.
(Source: Greif Bros. Corp., Delaware, Ohio, used with permission.)

TABLE 7.4. Fibre Drum Preferred Diameter/Capacity Relationship.

Dimension Range		Capacities in Gallons														
Minimum Internal Drum Diameter (in.)	Maximum External Drum Diameter (in.)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
11.0	12.5	X	X													
14.0	15.5	X	X	X	X											
15.5	17.0		X	X	X	X										
17.0	18.5				X	X	X									
18.5	20.0					X	X	X								
20.0	21.5							X	X	X	X	X				
21.5	23.0								X	X	X	X	X	X		
23.0	24.5										X	X	X	X	X	X

Note: For selected capacity and dimension range, the drum diameter dimensions will be in the range specified. The height dimensions will vary according to the diameter selected in the range.

Source: International Fibre Drum Institute, Washington, DC.

If this level of protection is not required, plastic ends or metal slipcovers are less expensive. For dust protection, a liner bag may be adequate at a lower cost than the gasketed metal cover.

With the great variety of sizes available, it is possible to get two or three drums of the same capacity but with different dimensions. The merit of this is that shipping and storage space can be saved by nesting the drums. For example, 55-gal (208.2-L) fibre drums are available in 21.5-, 23-, and 24.5-in. (54.6-, 58.4- and 62.2-cm) diameters (see Table 7.4) [7]. The savings in storage and shipping costs will more than offset the inconvenience of denesting and having to fill and stack drums of different heights.

References

1. International Fibre Drum Institute. 1994. *American Standard for Fibreboard Drums with Locking Band Closure,* p. 5.

2. American Trucking Associations. 1996. *National Motor Freight Classification 100-W.*

3. National Railroad Freight Committee. March 7, 1994. *Uniform Freight Classification 6000-K.*

4. *American Standard,* op. cit., Figure 1.

5. *Uniform Freight Classification,* op. cit. Reference [Ref. 3].

6. *Motor Freight Classification,* op. cit. Reference [Ref. 2].

7. *American Standard,* op. cit., Table 1.

Chapter 8— Plastics

General Background

Shipments of plastic packaging materials have increased in recent years at rates averaging about 12.3 percent—roughly four times the average annual growth rate for all other packaging materials [1].

Packaging is the largest user of plastics in the United States, accounting for 27.1 percent of the approximately 71.2 billion lb (32.3 billion kg) distributed in 1996 [2]. This amount is divided between thermoplastics at 19.3 billion lb (8.8 billion kg) and 58 percent and thermosets at 48 million lb (21.8 million kg) and 42 percent [3].

A major reason for the rapid growth of plastics is the versatility these materials offer to designers—ease of shaping, light weight, resistance to breakage, brilliant colors, crystal-clear transparency, and a warm feel that enhances sales appeal.

Another reason is that, despite the increasing costs of plastic resins, the cost/function ratio for plastic containers remains high.

The whole complexion of packaging was changed with the introduction of plastics. Not only are the materials themselves different, but so are the methods of manufacture and use. Fabrication of plastics for packaging has spawned such hitherto unknown techniques as extrusion and orientation, injection and blow molding, rotomolding, thermo- and cold-forming, ultrasonic and high-frequency sealing, and spin-welding.

Methods for alloying, chemically combining, and orienting many plastic materials have been developed, which constantly create new materials with more useful physical and cost-effective properties. More efficient extrusion screws and dies are providing better films and coatings. Coextrusion of dissimilar plastics has greatly multiplied the capabilities of films, coatings, and containers, both semirigid and rigid.

There are some sobering aspects to plastics along with these advantages. The present mood of the public is to once again condemn anything that they perceive contributes to pollution of the environment and expansion of waste-disposal tonnages and costs. The litter that is much in evidence along city streets and highways consists largely of packaging materials. Landfills are closing and there is general reluctance to start new ones. Because of their success in packaging and a strange public perception about their "artificial" nature, plastics have taken the brunt of criticism by environmentalists.

However, this time around (the first environmental packaging wave was in the late 1960s and early 1970s), industry leaders in end-user and supplier companies and their associations have moved more quickly to minimize the amount of plastics in packaging, eliminate nonessential components, and create recycling systems, which are transforming the raw-materials sources for packaging. It is a conservation movement that has long been needed and, when it finally settles down, will provide substantially increased economy in the overall utilization of natural resources. This is particularly important with plastics, most of which come from sources that are somewhat finite in quantity (for more details, see Chapter 21, Packaging and the Environment).

History

Plastic connotes the ability of a substance to be molded. Originally, such materials were natural compounds. Synthetic plastics are a relatively new development mostly based on monomers (molecules) containing carbon, which has a facility for repetitively bonding with other atoms to create plastic polymers.

To trace the development of the plastics industry, we must go back to 1843 when Dr. Montgomerie, a Malaysian surgeon, reported that Malayans were using gutta-percha (a white to brown latex sap from local trees, similar to rubber) to produce knife handles and other useful articles. This led to formation of the Gutta Percha Co. for production of picture frames, ink stands, and billiard balls. This was 30 years before Hyatt's famous search for a new billiard-ball material.

At about the same time, Alfred Critchlow of the Pro-phy-lac-tic Brush Co. in Florence, Massachusetts, developed dies and presses to mold shellac compounds, straw pulp, and gutta-percha into buttons, checkers, and personal articles. During the Civil War, a shortage of ivory for billiard balls caused the firm of Phelan and Collander to offer $10,000 for a substitute material.

This came to the attention of John Wesley Hyatt, an engineer working as a printer in Albany, New York. After several years of experimenting, he applied for a patent which described the unique and critical action of camphor on pyroxylin made from cotton and nitric acid. This material could not be molded, but was cut and shaped in the same manner as ivory. On the basis of his patent, Hyatt formed the Albany Billiard Ball Co. When the factory was moved from Albany to New York City, the name was changed to the Celluloid Manufacturing Co. The name *celluloid* was coined by John's brother, Isaiah Smith Hyatt, who worked with him on many of his experiments.

Forty-one years passed before the plastics industry made its next major step forward. In 1909, Dr. Leo Hendrick Baekeland, after much experimentation, was able to obtain a controllable reaction between phenol and formaldehyde. Many other researchers had tried to combine these materials but were unable to produce a useful product. At the age of 35, Dr. Baekeland dedicated himself to solving the phenolic resin enigma and after four years of intensive work, discovered the value of hexamethylenetetramine as a catalyst and the need for pressure to stop a foaming reaction. The resulting material, called Bakelite after its inventor, was the first synthetic resin and the start of the synthetic plastics industry. Other plastics followed in rapid succession: casein-formaldehyde in 1919; alkyd and aniline formaldehyde in 1926; cellulose acetate and polyvinyl chloride in 1927; and urea formaldehyde in 1929.

For the packaging industry, the real breakthrough came with the invention of polyethylene (PE) in England. In December 1935 chemists working in the laboratories of Imperial Chemical Industries reacted ethylene under high pressure with the chance addition of a small amount of oxygen. The resulting material was found to have good electrical insulating properties and, during World War II, large quantities were used for coating military communications wire and the paper wrappings for small arms. Extruded film was made from PE as early as 1945, but it was not very transparent, was subject to stress cracking, and difficult to print. For details on plastics in flexible packaging, see Chapter 3, Films and Foils and Chapter 4, Coatings and Laminations.

At the end of the war, demand dropped sharply and producers looked for other uses. A method for blow molding plastic articles, which combined extrusion and molding processes, had been developed by Enoch T. Ferngren and William Kopitke, and they sold their idea to the Hartford Empire Company in 1937.

The existing low-density polyethylene (LDPE) proved to be a functional material and a squeeze bottle for Stopette deodorant was introduced around 1947. In 1953 Dr. Karl Ziegler invented a process for making PE using a catalyst of titanium tetrachloride and triethyl aluminum. This process did not require high pressures to force the reaction. The result was a higher density polyethylene, which permitted bottles to be blown with thinner walls. By 1959 five companies were making detergent bottles of high-density polyethylene (HDPE). From these early starts, the processes for creating many different plastics as well as methods of extrusion, molding, and forming have proliferated, producing an endless variety of shapes and forms.

In 1995 packaging usage of major plastics broadly broke down into 10.8 billion lb (4.9 billion kg) for rigid containers and components, 7.6 billion lb (3.4 billion kg) for films, 1.1 billion lb (500 million kg) for coatings, and 150 million lb (68 million kg) for adhesives [4].

For the major types and amounts of plastics used in packaging, see Table 8.1. From these data, it is obvious that the "polyolefins" are the workhorses of the industry. Very-low-, low-, and linear-low-density PE, HDPE and polypropylene (PP) represent about 47 percent of the plastics used for packaging. Polyvinyl chloride (PVC) and polystyrene (PS) are still strong, and the use of nylon in films and polyester in both rigid and film applications is growing rapidly. Perhaps the greatest growth now and in the future are blends of different plastics to obtain multiple properties and benefits.

General Chemistry

The word *polymer* is made up of poly, meaning many, and mer from the Greek word *meros,* meaning part; hence, many parts. So, a polymer is composed of a large number of parts connected together in an orderly fashion

TABLE 8.1. Principal Packaging Plastics Used in North America in 1995.

Plastic	Weight (million lb)
Epoxy	28.9
Nylon	99.7
Polyester	2,226.6
Polyethylene	
Low Density	64.2
Linear Low Density	3,208.4
High	6,169.4
Polypropylene	2,284.4
Polystyrene	1,394.2
Polyvinyl Chloride	742.7
Miscellaneous	5.4

Miscellaneous includes phenolic, urea, melamine, styrenic, and engineering resins.

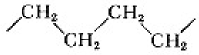

Figure 8.1.
A short-chain polymer.

forming molecular chains. Small parts are very often gaseous or liquid and transformed into solids by combining or polymerizing, the basis for all plastics technology.

Carbon atoms have four points of attachment to each other or to atoms of other materials. Thus, we can write the formula CH_4 to indicate that four atoms of hydrogen are attached to one atom of carbon to form a molecule of the gas, methane, which is called a monomer. The connecting points are equally spaced around the carbon atom, 109 28' apart and not in the same plane. When carbon atoms hook onto each other, they form chains that have a zigzag pattern, which is called a polymer, as shown in Figure 8.1.

When the chains are grouped together in a random pattern like a pile of straws, they are said to be “amorphous.” If packed nearly parallel in an orderly arrangement, the material is more crystalline in nature, has a higher density, and is stiffer and tougher. Sometimes, the chains have side chains (see Figures 8.2 and 8.3). PP is such a plastic. Branching chains prevent the molecules from packing closely together and, thus, lower the density of the plastic. PE, for example, can have a specific gravity ranging from 0.900 to 0.980, depending upon its structure and degree of branching and crystallinity (see Figure 8.4). These types of plastics are easily melted and remelted and, therefore, are classified as “thermoplastics.”

If such side chains become connected or “cross-linked,” the plastic takes on a partial characteristic of a “thermoset” (see Figure 8.4). A thermoset material can be melted only once.

Combinations of different atoms make up various other plastics: PVC —CH_2—CHCl— or polyvinylidene chloride (PVDC) —CH_2—CCl_2— for example. But they all have one thing in common: the capability of “condensing” into very long chains under the right conditions.

The simplest molecules are composed of only hydrogen and carbon and are called hydrocarbons. Common names for these materials are based upon the number of carbon atoms in each molecule; thus, ethane, propane, and butane have two, three, and four carbon atoms, respectively. If the molecule is “unsaturated,” that is, has a double bond between two carbon atoms, the names change to ethylene, propylene, and butylene.

When unsaturated compounds open up their double bonds under heat, pressure, and, generally, the presence of a catalyst, the resultant polymerization of these monomers yields PE, PP, and polybutylene. This kind of poly-

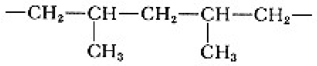

Figure 8.2.
PP chain with branches.

merization is called "addition polymerization," since there are no byproducts, in contrast to "condensation polymerization," in which the molecules combine with the loss of a simple compound such as water.

A "catalyst" is a compound that promotes polymerization, but generally does not take a chemical part in the reaction. However, it has a great influence on the properties of resultant polymers. Conventional catalysts are the chromium-based and silica-supported catalysts used to make HDPE (Phillips Petroleum Co., Bartlesville, Oklahoma, technology) and titaniumbased catalysts (Ziegler-Natta technology) used to make linear PEs and PPs. The surfaces of these catalysts have many sites, which promote polymerization. However, since the activity level of these sites varies, the ethylene molecules string together at different rates. This produces plastics with different molecular weights and properties.

A dramatic improvement in polyolefin film properties has resulted from a new family of catalysts called "metallocenes" (meh-TAL-o-seens), which are said to be a mixture of such metals as zirconium and titanium with oligomeric alumoxane cocatalysts. Like their predecessors, the metallocenes have many reactive sites. However, with the metallocenes, all the olefin molecules come together in the same way, hence their designation as "single-site catalysts." Films and molded structures made from these resins show dramatic increases in puncture, tear, and tensile strength. Currently, high cost (as much as double that of conventional olefin resins) restrict their use to critical applications. However, in the time-honored fashion of the plastics industry, prices are already falling as producers learn more about how to handle the new catalysts and film extruders and molders adapt their equipment and processes to effectively accommodate these somewhat new plastics.

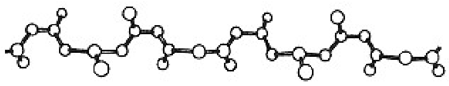

Figure 8.3.
Some plastic molecules consist of a chain of carbon atoms with hydrogen or other atoms attached and may have side branches as shown. The four connecting points around each carbon atom are equally spaced in all directions, resulting in a spiral configuration of the chain.

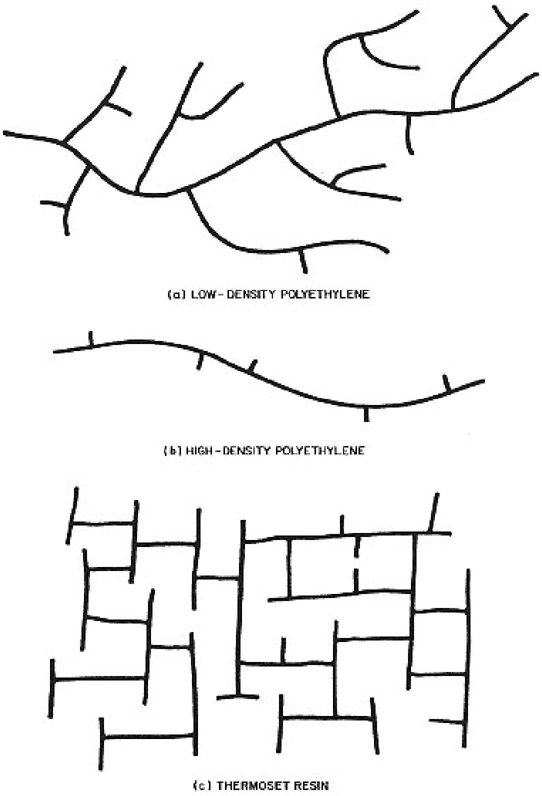

Figure 8.4.
The molecular structure of LDPE shows a highly-branched chain (A), making it a flexible, stretchable material. HDPE with its more linear structure (B) allows a tighter packing of the molecules, resulting in a denser, stiffer material. Cross-linking of the chains (C) produces a hard, unmeltable material.

Changes in basic polymers also can produce profound changes in the resultant plastics. Another recent development in this regard is the use of so-called super-hexene (six-carbon molecule) and super-octene (eight-carbon molecule) comonomers, which create much tougher linear-low-density polyethylene (LLDPE) than that from standard butene (a four-carbon molecule). Still another new approach is the production of a bimodal type of LLDPE, reportedly by mixing the output of two reactors. It not only is as easy to process as LDPE but also has superior strength. These advances will be necessary if the package downgauging trend continues in the name of cost and environmental conservation, and the addition of more recycled resin puts a premium on getting the most strength possible from the virgin portion of the mix.

The plastics discussed above are "homopolymers" or single plastic entities. However, it is also possible to combine two different plastics and create a "copolymer." In these multiple chemical combinations, the proportions are not usually equal. The major portion is called the "base monomer" and the smaller amount the "comonomer." The properties of the combination will depend on several factors. The proportions of the component materials are the most important, but the type of comonomer, and the way it is processed also contribute to the character of the final product. For example, butadiene and styrene might combine in a regular pattern, as:

—Bu—St—Bu—St—Bu—St—

or in a more random configuration, as:

—Bu—Bu—St—Bu—St—St—St—Bu—

It is also possible to hitch three different plastics together to create a "terpolymer" (Figure 8.5). This provides a combination of desirable properties not available in any single homopolymer. One example is acrylonitrilebutadiene-styrene, commonly referred to as ABS. Here, too, the molecular pattern can be regular, but is more likely to be a random configuration, as:

—Bu—Bu—St—Ac—St—St—Bu—Ac—Ac—St—

Blends of two or more mutually soluble resins (melt-blending is often more functional than dry blending) also can add desirable properties to a plastic or reinforce existing ones. Such blends generally are more flexible, stronger, and tougher than they would otherwise be and do not have the exudation, migration, and leaching problems associated with plasticizers. An example is the addition of the relatively new liquid-crystal polymers (aro-

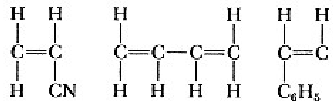

Figure 8.5.
Terpolymers have three components as shown in the diagram of ABS.

matic polyesters) to conventional polyester resin for film or rigid containers. These are extraordinary polymers with barrier properties equivalent to conventional ethylene vinyl alcohol (EVOH) and PVDC, tensile strengths exceeding that of steel, resistance to virtually all substances that attack other packaging plastics, negligible creep, and heat tolerance approaching 500 F (260 C). Despite current high costs, so little of this engineering plastic is needed to improve the above properties in packaging polyesters that development for films and bottles is going forward.

Other chemicals that add or enhance various desirable properties in a plastic are additives such as plasticizers, antioxidants, slip agents, ultraviolet (UV)-light degradation inhibitors, and fillers of various kinds.

Vinyls are normally rigid, but with the addition of plasticizers become soft and pliable, and their usefulness is greatly extended. PP would have a very short life were it not for antioxidants, which are added during processing, and a succession of improved clarifying agents that have dramatically enhanced both the organoleptic properties and clarity of this important packaging material. Glass fibers used as filler will double the strength of most plastics. Other low-cost fillers add stiffness or sometimes simply bulk, displacing some of the more expensive resin and, thus, reducing the cost of the finished piece.

General Properties and Testing

The choice of plastics to be used for a particular application will be governed by a number of considerations. First, the environmental conditions of packing, storage, and shipment should be taken into account. The material must have the physical strength to protect the contents from mechanical damage and atmospheric conditions.

To assess this, it is necessary to study the packaging material's tensile and impact strengths and permeation rates to moisture and gases. Chemical compatibility with the product or any other components of the package is also important. The information in Table 8.2 can be used as a starting point. For more detailed data, see the discussion of the individual plastics used in

TABLE 8.2. Properties and Costs of Packaging Plastics.

		Gas Permeability			Chemical Resistance†		
Material	WVTR	O_2	N^2	CO_2	Acids	Alkalies	Solvents
Acrylonitrile	5	0.8	0.2	1.2	G	E	E
Phenolic	—	—	—	—	F	F	G
Polycarbonate	11	300	50	1000	G	P	F
Polyester‡	0.7	14	0.7	16	E	E	E
Polyethylene, HD	0.3	600	70	450	E	E	E
Polyethylene, LD	1.3	550	180	2900	G	G	G
Polypropylene	0.7	240	60	800	G	E	E
Polyvinyl Chloride	4	150	NA	970	E	E	F
Styrenics							
GPPS	8	310	50	1050	G	E	P
ABS	12	100	—	—	G	G	F
SBC	6.8	500	65	2170	G	G	P
Urea	—	—	—	—	F	F	G

Table 8.2. (continued).

Material	Service Temp.	Clarity	Printability	Dust Attract.	Mar§ res.	Warpage§§
Acrylonitrile	-100–160	Transp.	G	High	60	0.004
Phenolic	-100–250	Opaque	G	Low	120	0.010
Polycarbonate	-210–270	Transp.	E	Med.	118	0.006
Polyester	-70–230	Transp.	F	Med.	68	0.020
Polyethylene, HD	-20–250	Transl.	F	High	38	0.040
Polyethylene, LD	-70–180	Transp.	F	High	112	0.030
Polypropylene	-20–200	Transp.	G	High	110	0.020
Polyvinyl Chloride	-50–200	Transp.	G	High	80	0.005
Styrenics						
GPPS	-80–175	Transp.	G	High	90	0.020
ABS	20–140	Transl.	F	High	100	0.006
SBC	-40–120	Transp.	G	Low	70	0.010
Urea	-100–170	Transl.	G	Low	150	0.010

(continued)

TABLE 8.2. (continued).

Material	Stiffness	Impact strength 2	Tear strength#	Brittleness##	Cost $/lb	$/in^3
Acrylonitrile	490	2.5	60	5	1.30	,0.054
Phenolic	1000	0.5	—	1	0.84	0.043
Polycarbonate	340	3	25	75	2.10	0.091
Polyester	550	4.8	40	100	0.52	0.026
Polyethylene, HD	150	10	30	100	0.54	0.018
Polyethylene, LD	10	20	100	400	0.58	0.019
Polypropylene	200	1	25	300	0.53	0.017
Polyvinyl Chloride	378	8	90	20	0.45	0.021
Styrenics						
GPPS	750	0.3	—	1	0.46	0.017
ABS	300	7.7	—	60	0.90	0.034
SBC	215	0.8	—	160	0.955	0.035
Urea	1000	0.4	—	1	0.90	0.048

g/24 h/100 in.^{2}/mil @ 95 F, 90% RH.

Izod impact strength, ft lb/in., notched.

cm^3/24 h/100 in.^{2}/mil @ 77 F, 50% RH.

#Elmendorf, g/mil.

† Excellent, Good, Fair, Poor.

##Elongation @ breaking point in % of length.

‡ Bottle resin.

Chemical resistance Good, Fair, Poor

§ Rockwell hardness, R scale.

Clarity transparent or opaque

§§ Mold shrinkage, in./in.

Printability Low, Medium, High

Flex modulus, psi.

Dust attraction Low, Medium, High

packaging, which starts on page 228. If this is not sufficient, then it is necessary to consult textbooks on the subject or suppliers.

Next, look at the form of material that is required. If it is to be used as wrapping, it must be available as a film. A package for liquids and powders will require a secure closure, which can be obtained with film bags and pouches, blown bottles, extruded tubes, thermoformed blisters, and heat-sealed trays. A rigid container, which must perform certain mechanical functions, may require injection- or compression-molded parts. Each of these considerations places limitations on the type of material that can be used. Cost is always a strong consideration and, when noted in conjunction with the description of physical properties in Table 8.2, will aid in selection of the optimum material for the purpose.

If the product comes under federal or state regulations, there are always limitations in the types of materials or containers that can be used. Regulations for toiletries and cosmetics are fairly simple, but food, pharmaceutical, and hazardous-material packaging can be very complex (for more information, see Chapter 20, Laws and Regulations).

On the basis of physical requirements for a package, a process of elimination may be helpful in selecting the right material. For example, if elasticity is needed, then consider the polyolefins, vinyls, synthetic rubbers, and elastomers. For high-temperature requirements, the choice is limited to acetal, nylon, polycarbonate (PC), polyester, and the thermosets. Impact resistance is a different thing. The tables do not always correlate with actual experience, so samples should be rigorously tested before a final selection is made.

Color is no problem with any of the thermoplastics and almost any hue or tint can be had, and thermoset urea is widely compatible with different colors. Thermoset phenolics, though, are limited to dark colors. If transparency is the goal, then use one of the cellulosics, PS, phenoxy, vinyl, acrylic, or some of the clarified olefins.

For moisture resistance or retention of moisture, the polyolefins are good, particularly when enhanced with a coating or extruded layer of PVDC, ethylene vinyl-acetate copolymer, or ionomer.

Chemical resistance varies and is discussed later in this chapter under each material. Do not overlook the synergistic effect of chemical combinations, which separately would not be a problem.

Grease resistance or retention of oily products is the province of vinyls, but cellulosics also can be considered along with ionomers. The protection of odors and flavors is particularly difficult and although gas permeation data will provide some guidance, careful tests over a long period of time are very important. The problem here is that selective loss of some aromatics or portions of an aromatic can result in a disagreeable odor or flavor. Further discussion will be found under the individual plastics.

Tests should always be performed at room temperature and also at the extremes of temperature the package will experience in the commercial environment. Such tests should continue for a month at the least and, preferably, much longer. Conditions of testing should closely simulate the actual service environment, including motion, impact, storage positions, light, temperature cycles, and humidity. There are strange reactions between packages and their contents.

These tests are based on reproducible methods, which have been developed over a long period of time and can be duplicated in any well-equipped laboratory. The data shown in Table 8.2 cannot always be directly related to service conditions, however, and must be interpreted in terms that are applicable to the packaging problem at hand. It should also be kept in mind that these figures apply to laboratory tests conducted under very specific conditions and on very specific plastic formulations. Any change in the test conditions or in the source and chemistry of an individual plastic will alter the results. For this reason, the figures listed in other texts may not always agree with the values noted in this book.

In comparing the costs of different plastics, the figures in Table 8.2 and in the sections about individual plastics are current as of this publication date. While there are always fluctuations in the market, the *relative* positions of plastics on the cost scale actually vary very little. Thus, these figures can be used to calculate "budget" costs and comparisons between different plastics. For close figuring, it is necessary to request the latest prices from suppliers. For principal packaging films, properties are described in Table 3.5 in Chapter 3, Films and Foils. Film costs are charted in the same chapter in Table 3.1.

Plastic Properties

A review of the features described below shows that these properties can work at cross purposes. Therefore, a processor must balance the fundamental polymer properties to favor characteristics that are essential to a particular application. Additives, copolymers, and blends can help improve other needed characteristics.

Stiffness

The wall thickness of a container is often dependent upon the stiffness of the plastic. As shown in Table 8.2, HDPE is much stiffer than LDPE. Even though the high-density material is more expensive, a container made with it often costs less because thinner walls require less material.

Clarity

Since many packaging applications require contents to be visible, the relative transparency of the different plastics is of considerable interest. The values shown in Table 8.2 are for a fairly thick sheet. A thin film, of course, will be much more transparent. Surface luster varies among the different plastics, but this was not taken into account in this table. The transparency ratings are based strictly on light transmission.

Mar Resistance

Packages are subjected to many kinds of hazards in manufacture, on the filling line, and in shipment. The resistance of the various plastics to scratching, scuffing, denting, bruising, and abrasion is summed up in Table 8.2 under the heading "Mar Resistance." The appearance of a container at the point of sale also will depend on whether it is transparent or opaque, since clear materials tend to show defects more obviously than colored.

Warpage

The tendency of rigid plastic containers to warp is a function of shrinkage in and out of the mold. Thick sections shrink more than thin, and parts remote from the gate in the mold are more affected than those close by. Shrinkage also will vary with mold temperatures and pressures, but basically it is a function of the molecular structure of the polymer.

Temperature Range

Outdoor variations in temperature that a package is likely to encounter in this country generally range between -20 and 120 F (-29 and 49 C) but can be even colder or hotter on occasion. Temperatures inside and near the top of trucks parked in areas of the Southwest at midday have been measured at 135 F (57.2 C). Storefront window displays can expose packages and products to the heat of direct sunlight and UV radiation. The figures in Table 8.2 give practical service temperature ranges, which also assume that the package may be under stress from stacking, tight closures, or abusive handling at these extremes.

Water-Vapor Transmission

The watervapor transmission rate (WVTR), sometimes called moisturevapor transmission rate (MVTR), is the measure of gain or loss of water through the walls of a package. In actual storage, this will vary according to the season of the year, the average humidity being considerably higher in the summer than in the winter. Higher temperatures also will accelerate the passage of moisture through a permeable package. The figures in Table 8.2 are for 1-mil (25.6- m) film. For heavier gauges, WVTR has an almost direct relationship to thickness. With materials that contain plasticizers and other additives, the transmission rate may differ from the figures shown, usually higher, as these values are based on unplasticized resins. Pressure differences do not have any effect upon the rate of transmission.

Gas Permeability

The rates shown in Table 8.2 for the transmission of gases through the various plastics are also based on 1-mil (25.6- m) film. The rate declines almost proportionately as thickness increases; that is, twice the thickness gives about half the transmission rate. The permeation rates for gases are independent of pressure, but temperature can be an important factor, especially for those materials with the lowest rates. Combinations of gases act independently and transpire through the plastic as though they were alone. The most important gases and their rate of transmission from a packaging standpoint are oxygen (O_2), nitrogen (N), and carbon dioxide (CO_2) for both their necessary presence or their deleterious effect in some types of products.

Solvent Permeability

Since permeation is one of the most important considerations in the selection of a plastic container, an explanation of this phenomenon might be in order. A liquid or gas must go through four phases in passing through a plastic barrier: (1) Absorption into the plastic at the interface, which is governed by surface tension, vapor pressure, and the shape of the molecule; (2) Solution of the permeant into the plastic, determined by the difference in the polarity of the permeant and the plastic (the greater the difference, the slower the rate of solution); (3) Diffusion of the permeant from one side of the plastic wall to the other, which will depend upon the shape of the molecule and its polarity and, of course, on the thickness of the plastic wall; and (4) Evaporation or desorption from the surface on the other side. Like (1), this will be a function of surface tension, vapor pressure, and the shape of the molecule.

The polarities of the permeant and the plastic will have the greatest effect on the rate of diffusion. A highly polar liquid will permeate a highly polar plastic 100 times faster than a nonpolar liquid. The reverse is true if the container is nonpolar. In this case, a nonpolar liquid will diffuse very rapidly. This follows the familiar rule of the chemist that “like permeates like.” Examples of liquids with low polarity are aliphatic hydrocarbons and ethers.

Medium-polarity liquids are esters, ketones, and aldehydes. Highly polar solvents include alcohols, acids, and water. Among the plastics, polyolefins are completely nonpolar, vinyls are moderately polar, and PC and nylon are very polar.

Migration

The actual polymers used in packaging are insoluble in foods, beverages, or pharmaceuticals. However, the great number of plasticizers, antioxidants, lubricants, and UV inhibitors that are used sometimes cause problems. Leaching of plasticizers by liquid products can have an unfavorable effect on the container, causing embrittlement and rendering the package unserviceable. The use of PVC in beverage bottles was banned at one time because unpolymerized monomer was extracted by the contents.

In the other direction, it is possible for preservatives in foods and pharmaceutical products to be absorbed into the plastic, leaving the product unprotected and subject to spoilage. PE milk bottles cannot be reused because butterfat gets into the plastic and becomes rancid.

Since the possibilities—given the number of different product formulations and chemical combinations in plastic containers—is virtually infinite, every product and its plastic container should be thoroughly tested before marketing.

Chemical Resistance

The effect of a chemical product on its package varies with each plastic, sometimes causing swelling and softening or stickiness on the surface. At other times the result is a structural weakening, which leads to stress cracking, or it may be a stiffening effect due to the removal of plasticizer. Table 8.2 notes the general resistance of packaging plastics to common classes of strong chemicals. Table 8.3 lists chemicals that may have an adverse effect on plastic packaging.

Tensile Strength

As an indication of the resistance of a material to continuous stress (a screw cap on a bottle, for example), the tensile strength is a good criterion. PE with a tensile strength of 1,000 psi/mil (6.9 MPa) is only fair as a binding material. On the other hand, nylon with a strength of 10,000 psi/mil (69 MPa) adds great strength to packaging films and containers.

Tensile strength will not show the effect of impact on a plastic container, however. For this, it is necessary to consider the modulus of elasticity, which

TABLE 8.3. Chemicals That May Be Incompatible with Certain Plastics.

Hydrocarbons	Esters
Benzine	Ethyl Acetate
Turpentine	Methyl Salicylate
Hexane	Amyl Acetate
Kerosene	Tricresyl Phosphate
Toluene	Essential Oils
Gasoline	Camphor Oil
Xylene	Orange Oil
Naphtha	Cinnamon Oil
Chlorinated Hydrocarbons	Peppermint Oil
Carbon Tetrachloride	Citronella Oil
DDT	Spearmint Oil
Chloroform	Eucalyptus Oil
Ethylene Dichloride	Turpentine Oil
Ketones	Lemon Oil
Acetone	Wintergreen Oil
Methyl Ethyl Ketone	

is the ratio of stress to strain. This modulus provides a measure of toughness, as it indicates how much the material yields to the applied forces by stretching instead of breaking.

Tear Strength

Although it is a combination of tensile, shear, and elastic properties, the tear strength of a plastic film or sheet can be very accurately measured. It is quite important to have this information to determine not only the processing characteristics, but also the shipping qualities of the package and the ease with which the customer can open the package for use. The figures in Table 8.2 are based on the Elmendorf tear from a notch. For data on tear strength of other common films, see Table 3.5 in Chapter 3, Films and Foils.

Impact Strength

There are various ways of checking the impact resistance of plastics. The figures shown in Table 8.2 are based on the Izod test, using notched pieces that are struck with a swinging weight. This is not the same as dropping a filled container on a hard surface, but is a more reproducible test and a reasonably good comparison. It should be noted that variations in thickness may not give the expected differences in impact strength because of the “skin effect.”

Impact strength is not a good basis for a total comparison of plastic strength for packaging purposes. The Izod impact test measures the energy required to break a notched bar. Since some plastics are more notch-sensitive than others, the results can be misleading. Nylon and acetal are among the toughest plastics, but are notch-sensitive and have low Izod values. The impact test in this case only indicates the need to avoid sharp corners in the molding of these materials.

Elongation

The amount of stretch in a plastic material is a measure of its ability to conform to an irregular surface and absorb stresses without breaking. On the negative side, it also is the resistance of a film pouch or sealed blister lidstock to being opened easily by the consumer. Elongation is a good measure of toughness. Nylon, with 300 percent elongation, will not puncture easily. PS, with only 2 percent elongation, is quite vulnerable to such concentrated forces.

Density

This property involves the degree of compaction between molecules in the plastic. As density increases, hardness, stiffness, melting point, barrier properties, low-temperature resistance, tensile strength, abrasion resistance, and permeability generally increase, while impact strength and resistance to stress cracking usually decrease.

For all practical purposes, although slightly different, the density and specific gravity of a plastic can be used interchangeably in packaging. Expressed as g/cm^3, density is the weight of a specific unit volume of plastic at 23 C (73.4 F) Specific gravity is a pure number representing the ratio of a given weight of plastic to the same volume of water at 23 C. The reason for the difference is that water at 23 C is slightly less dense than 1.0. Where rigorous accuracy is required, the correct density is found by the formula

density = specific gravity   0.998

Melt Index

Melt Index (MI) is a measurement of the rate of flow of molten plastic through an orifice in the test apparatus (ASTM D 1238). The MI is also an indication of molecular weight, and a high MI corresponds to a low molecular weight. Usually, as molecular weight increases so does stiffness; tensile, and impact strength; abrasion, chemical, and stress-crack resistance; and hardness; while melting point, low-temperature brittleness, and permeability generally decrease.

Molecular Weight Distribution

Molecules in a plastic are not all the same size. A plastic with a narrow range of Molecular Weight Distribution (MWD) has more molecules of the same length than one with a broader MWD. Broad MWD plastics, in general, have lower impact and melt strengths and tend to warp, but processability and any tendency to stress crack usually improve.

Plastic Additives

Plastics for packaging contain other ingredients, too. The cost of these additives varies with the application and the plastic used but, generally, runs between 60 and 85 cents/lb today.

There are internal lubricants such as the predominant calcium stearate. A host of other chemicals are used in both PVC and other plastics as heat stabilizers and to promote fusion, decrease molecular friction, and modify melt viscosity. In addition, external lubricants decrease friction between resins and the processing equipment.

The action of light on plastics varies. The shorter wavelengths are much more destructive than the longer ones, and most of the damage comes from the UV part of the spectrum between 3,000 and 4,000 Å (0.3 and 0.4 m, 0.0003 and 0.0004 mm). For protection against UV rays the best bet is hindered amine light stabilizers (HALS). Against heat, organometallic and mixed metal stabilizers do the trick.

The function of heat stabilizers is to scavenge the hydrogen chloride that is liberated as a degradation product. They are nearly always used in conjunction with antioxidants. The amount of UV stabilizer used in a formula depends on the thickness of the finished part; thin sheets and films require a great deal more than heavy molded parts because of the greater area of exposure. These are expensive materials, typically $5 to $20/lb.

Of special importance in packaging are antistatic agents because films can hang up in wrapping and pouch machines and plastic film or molded packages tend to attract dust on store shelves. Styrenics are the biggest problem followed by acrylics and the PEs. The reason is that when two plastic surfaces are in contact, the electrons on the surface atoms intermingle and may move from one material to another. Pressure and friction between packages will increase the movement of electrons. When the two materials are separated, the one that has lost electrons is positively charged and the one that has gained electrons is negatively charged. When there is sufficient moisture in the air an ionization occurs that neutralizes or bleeds off these electrons.

The purpose of most antistatic agents, then, is to absorb moisture from the air to aid in this neutralization. There are two types of antistats, external and internal. One of the simplest ways to do this is with an external dip or spray of a 1 percent solution of a dishwashing detergent. Unfortunately, it is effective for only a few weeks. Internal antistats are compounded into the plastic resin and gradually migrate to the surface of the plastic package in a process called "blooming." These antistats, which are classed as cationic, anionic, and nonionic, afford much longer protection against static surface charges.

Cationic antistats, such as quaternary ammonium, phosphonium, or sulfonium salts, work best in such polar substrates as rigid PVCs and styrenes, but require high levels of concentration and are not Food and Drug Administration (FDA) acceptable for foods. Anionic antistats are also alkali salts and work similarly to the cationic materials. Sodium alkyl sulfonate has achieved the widest use among PVC, styrenes, polyethylene terephthalate (PET) and PC.

The largest class, nonionic antistats, are widely used in the PEs, styrenes, and PP. Ethoxylated alkyl amines are FDA-approved for indirect food contact and operate effectively at low conditions of humidity for prolonged periods of time. Other ethoxylated compounds are used where immediate and continuing action is needed in PEs and PP.

The amount of antistat used in food packaging is regulated by FDA and also is governed by the fact that excessive use can create a greasy surface on the package and affect its printability and the adherence of labeling adhesives.

Plasticizers

Plasticizers can functionally modify a plastic by reducing the processing temperature to avoid decomposition of the polymer and altering processing characteristics to make the finished product more soft and flexible. This is accomplished by acting as a partial solvent for the resin or as a lubricant that allows molecules to freely slide over one another. As a solvent, they break and replace some of the polymer-to-polymer bonds in the molecule with polymer-to-plasticizer bonds. Packaging plastics that are improved by plasticizers include PVC, which uses about 80 percent of the plasticizers made, acrylics, nylons, and urethanes.

However, plasticizers tend to exude over time or at elevated temperatures and may migrate from one plastic part or container to another if the two are in contact. Plasticizers also may be leached out by solvents or by a liquid product that acts as a solvent. The effectiveness of the plasticizer may vary according to temperature. Prices depend on the material, but the major types of plasticizers sell for between 76 and 85 cents/lb.

The most important class of monomeric plasticizers is the phthalates. Typical of this group is dioctyl phthalate, which has lost some use to linear phthalates and also polymeric phthalates. Specialty plasticizers are also replacing the general purpose types as the creation of quality plastics becomes more necessary and complex. The list is long and varied.

Fillers and Reinforcements

Cotton, talc, wood flour, glass fibers, and dozens of other materials can be used as fillers in plastics. Although used more consistently with thermosets, thermoplastic resins also can incorporate fillers with beneficial results. Fillers are chosen for different reasons: to reduce cost if the filler is cheaper than the resin; to add stiffness to a plastic that is too flexible; or to increase tensile strength by adding tough, fibrous materials. Fillers also reduce shrinkage in the mold, minimizing any tendency for warpage.

Selected Plastics for Packaging

Following are brief details on the common plastics used in packaging with respect to their chemical structure, characteristics, basic advantages and disadvantages, applications, and FDA approval. It is important to note that all plastics are constantly undergoing change and improvement. Therefore, it is necessary for the user to keep up-to-date by reading plastics publications and to source detailed information from suppliers.

There are countless numbers and variations of plastics used in packaging. However, the fundamental resins used in the largest quantities for films, sheet (for thermoforming), and molded articles are relatively few and, with few exceptions, are thermoplastic materials. Here is a listing of such important plastics for packaging in alphabetical order. It should be noted that the cost of the basic resin given in this section is only for “budget” and rough comparative purposes. The actual cost of a plastic package depends also on the type of a particular resin used, the number and amount of additives that it contains, the method of fabrication employed, and the specific design.

Acrylonitrile

Development of high-nitrile resins (HNRs) was really made feasible by the creation in 1957 of a lower cost, one-step process for the production of acrylonitrile (AN) by the Standard Oil Co. of Ohio (now BP America Inc., Cleveland, Ohio).

Chemistry

These polymers are distinguished by their base of a cyno (nitrile) group to form AN (CH_2 = CHCN), which is combined with other comonomers for processability (see Figure 8.5).

Most HNRs are copolymers of AN with styrene or with multipolymers that include methyl acrylate or XT Polymer. About 75 percent by weight of the copolymer is AN. To improve impact resistance, up to 15 percent rubber (butadiene) is often added to the formula (Figure 8.6).

In the two primary types of nitriles, the basic difference is the inclusion or exclusion of either methyl acrylate or styrene as a comonomer. Those which contain styrene are often called ANS (acrylonitrile styrene) resins. These should not be confused with styrene-acrylonitrile (SAN), which has a higher proportion of styrene. SAN has various packaging uses including foam cushioning (see Chapter 16, Cushioning).

An example of a resin which contains acrylate instead of styrene is a rubber-modified copolymer of AN and methyl acrylate. The acrylate makes the polymer a better gas barrier. On the other hand, this improvement reduces heat resistance to about 150 F (65.6 C).

Characteristics

Nitriles are noted for clarity, shatter resistance, and superior gas-barrier properties when AN content is high. As single-layer materials, HNRs are exceeded in barrier properties only by EVOH and PVDC copolymers.

Because of its resistance to creep at internal pressures of 120 psi (827 kPa) and hot fillability up to 190 F (87.8 C), AN was originally promoted as a beverage-bottle resin, but was denied this application by the FDA in 1977 because of AN migration into the product.

This situation was amended in 1984 following the assertion by the developer that an electron-beam treatment of the extruded preform just before stretch blow molding, reduces AN migration to an almost undetectable level. FDA concurred. Nitriles now are being used in blow- and injection-

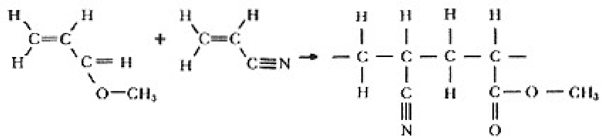

Figure 8.6.
Most nitrile resins are copolymers of acrylonitrile with either styrene or methyl methacrylate.
To improve impact resistance, there is also up to 15 percent butadiene rubber in the formula.

molded containers, film, and thermoformed-sheet applications for such typical products as prepared meats, cheeses, spices, household chemicals, and medical devices. In the meantime, however, plastic beverage bottles moved to PET.

The natural hue of AN is a light straw color, but blue-tinted-transparent or opaque resins are also available. For properties and cost data, see Table 8.2.

Advantages and Disadvantages

Nitriles were the first blow-molding resins adequate to retain carbonation in beverages and to retain flavors and fragrances in food and personal-care products. They also resist stress cracking with household chemicals and have moderately high heat-deflection temperatures for the hot filling of liquid products, good top-loading strength, and fairly good impact strength. No flame treatment is necessary before labeling, which generally is done with latex adhesives.

Sheet and film containers of HNR are used broadly for processed meats and condiments containing food oils, acetic acid, and preservatives.

Permeation to water vapor is not as good as PVC or polyester. Nitrile is difficult to blow mold, especially in the bottle finish area, and the trim is apt to be ragged. If regrind is used, it will cause yellowing. Since unoriented nitrile is as brittle as PS, it is important to stretch it in the blow-molding process, which greatly improves its properties.

Applications

The following materials are compatible with nitrile containers: most foods and beverages, naphtha, turpentine, shellac, cooking oils, moderately strong acids, and perfumed products. Chemicals that are not compatible include aromatic and chlorinated hydrocarbons, esters, ketones, strong bases, and solvents such as dimethyl formamide, acetonitrile, and tetrahydrofuran, particularly at elevated temperatures.

FDA Approval

These materials have been accepted by the FDA for food products, provided that AN extraction is held below 0.3 ppm (parts per million). FDA is continuing the study of AN copolymers for food contact.

Cellulosics

An early attempt in the late nineteenth century to make three-dimensional containers from the primitive plastics then available involved cellulose nitrate, a highly inflammable substance. Sheets of the material were clamped between the halves of steam-heated molds, which sealed the edges and expanded the material against the mold walls, a process discovered to be less than satisfactory and more than dangerous. In the 1930s with the invention of cellophane, cellulose acetate, cellulose propionate, and PS, automated molding equipment was devised by the now defunct Plax Corp. and Owens-Illinois, Inc., Toledo, Ohio.

Cellophane went on immediately to tremendous success as the first truly transparent packaging film (see Chapter 3, Films and Foils). However, limitations in properties and high costs prevented the creation of three-dimensional packaging containers made from cellulosics (although the process and the equipment later succeeded with the invention of PE).

Cellulose acetate, acetate-butyrate, propionate, triacetate, nitrate, and ethyl cellulose are all derived from cellulose by reacting it with anhydrides or acids. While some cellulosics are used in nonpackaging film, sheet, and injection-molded parts, very little or none are now used in packaging since these rather expensive materials must compete, today, with improved styrenics and polyolefins.

Fluoropolymer

Fluoropolymer film and sheet for packaging are highly specialized flexible and thermoplastic materials supplied exclusively by Allied Signal, Inc., Morristown, New Jersey, and used almost totally in the pharmaceutical and medical-products fields where a biochemically inert and very high-barrier package is essential for long-term shelf life.

Chemistry

This range of materials is made from fluorinated-chlorinated resins of three types: a homopolymer and two copolymers based on a modified polychlorotrifluoroethylene (CTFE). These films also can be laminated following two-side corona electrostatic treatment that raises the surface energy of the material.

Characteristics

CTFEs are crystal clear with a barrier to moisture and gas transmission that is higher than any other currently available packaging film. They are chemically stable and biologically inert, free from plasticizers and stabilizers, transparent to UV radiation, nonflammable, nonaging, and can be heatsealed with constant heat, thermal impulse, and ultrasonic techniques. CTFE is inert to acids and bases, stronger oxidizers, and most organic chemicals. The material should not be disposed of by burning, since it degrades to toxic fluorocarbon gases. For properties and costs of CTFEs, see Table 8.2.

Advantages and Disadvantages

For the ultimate shelf life, CTFE cannot be surpassed for long-term civilian and military medical packaging. There has been environmental concern, particularly in Europe because of the high halogen content of the material. However, for many ultrasensitive health products, there is no alternative at this time.

Applications

The material is extrudable as a film and thermoformable as a sheet for both pharmaceutical and medical-device packaging and is temperature resistant to sterilizing levels. It also can be printed, metallized, and laminated to paper and paperboard, other film, and aluminum foil.

FDA Approval

CTFE meets all applicable requirements for food and medical packaging.

Ionomer

DuPont Co., Wilmington, Delaware, discovered ionomers in the 1960s. A plastics family that resembles PE in fundamental properties, its differences have enabled it to carve out its own packaging niche.

Chemistry

Ionomers have been constructed from such basic materials as styrenes, butadienes, and fluorocarbons, but the original ethylene-methacrylic copolymer, neutralized with either zinc or sodium, is still the only significant ionomer in packaging. The high-pressure copolymerization process is similar to that for LDPE and is proprietary to DuPont.

Characteristics

Ionomer differs from LDPE in having significantly higher tensile and impact strength and toughness, a lower softening point, greater abrasion resistance, better oil and solvent resistance, greater clarity, and less haze. While LDPE seals very well, ionomer is surpassingly good with great hot tack, which enables it to seal through product particles. The material has outstanding low-temperature flexibility and does not require plasticizers.

Sheet for thermoforming absorbs and gives up heat faster at a lower temperature and possesses better hot-draw strength, as well. Ionomer can be processed on LDPE equipment.

For more details of properties and costs, see Table 8.2, as well as Tables 3.1 and 3.5 in Chapter 3, Films and Foils and Chapter 4, Coatings and Laminations.

Advantages and Disadvantages

Despite all of the advantages cited above, ionomer has a downside. As a film, it is poor in slip (film-to-film movement) and block (sticking to the adjacent film surface, particularly in rolls). High-temperature sensitivity is another fault. The material is more viscous than LDPE at lower temperatures and processing temperatures above 600 F (316 C) should be avoided. The material is also low in stiffness, susceptible to creep, possesses a low heatdistortion temperature, and requires stabilizers to resist UV radiation. About a dozen grades of ionomer are used in packaging, each formulated to boost a given set of the above advantages and to minimize the drawbacks.

Application

Ionomer is used extensively as film and in extrusion and coextrusion coatings

FDA Approval

All packaging grades of ionomer have approval for use with foods.

Nylon

Known also as polyamides, nylons are strong, tough thermoplastics with good clarity and temperature resistance in a range from -60 to 300 F (-51 to 149 C). They are also strong barriers to greases, fats, gases, and aromas. Nylons can be extruded, thermoformed, or molded and have had increasing use in food, medical, and chemical packaging applications.

Chemistry

The characteristic chemical structure of nylons is a repeating amide group, —CONH— and the different grades are identified by the number of carbon atoms in caprolactam or the particular diamine and dibasic acids used to formulate particular nylon grades. For example, nylon 6 is created from the caprolactam molecule by removal of a water molecule.

Nylon 6,6 is made by combining diacid and diamine in boiling methanol, which precipitates an insoluble salt. Then, a 60 percent solution of the salt in a small amount of acetic acid is reacted for three hours under a highpressure nitrogen atmosphere to build up molecular weight. The resultant molten polymer is extruded onto a chilled roll. Although normally crystalline in nature, nylons also can exist in the amorphous state.

Characteristics

There are a number of nylon grades. The most common ones used in packaging are nylon 6 biax, nylon 6, and nylon 6/6. All three are structurally strong, have relatively low moisture absorption, good dimensional stability, and heat-sealability, are comparatively economical and easy to process. Nylon 8 is also heat-sealable and can be cross-linked. Mono- or biorientation will increase favorable qualities. For more details on properties and costs, see Table 8.2 and Tables 3.1 and 3.5 in Chapter 3, Films and Foils.

Advantages and Disadvantages

Most nylons are clear and have good barrier properties to gases, strong mechanical properties, and excellent stability at both high and low temperatures, enabling hot filling in molded containers and freezer storage for food products. Nylons can be readily extruded into films and sheet, thermoformed, and blow molded. However, nylons must be protected from water absorption in storage, dried before processing, and protected from long exposure to high temperatures in processing, which can oxidize the material, causing it to lose strength. Stabilization of the resin can guard against this occurrence.

Applications

Nylon is easy to extrude and has been run successfully on PE extruders with only minor modifications. Nylon 6 frequently is coextruded with polyolefins to enhance desirable packaging properties, but also is used as a coating on paperboards, paper, and foils. Nylon film can be produced either by casting or blowing. Oriented films have even greater strength, toughness, and barrier properties. Extrusion-blow-molded containers for hard-to-hold chemicals are made by blending high-viscosity amorphous nylon with a polyolefin. Thermoforming by conventional methods is readily achievable due to nylon's high elongation, which permits deep draws and its resistance to stress cracking during and after forming. The less-crystalline copolymers provide better forming and greater clarity and are used in both film and sheet.

FDA Approval

Nylons meeting the compositions and solvent extractables listed in CFR 21, Food, Part 177.1500 may be safely used to produce articles used in processing, handling, and packaging of foods.

Phenolic

The earliest plastic to achieve broad commercial use was the thermoset, phenol formaldehyde. Dr. Leo Hendrik Baekeland of Yonkers, New York, is credited with the first practical application of this material in 1907, and the trade name Bakelite has since become a household word. Phenol formaldehyde had been known as a laboratory curiosity more than 50 years earlier, but Baekeland learned how to control the reaction with catalysts. He also introduced the use of fillers to improve the physical properties of the finished product.

Among the thermosetting plastics, phenolics have the widest acceptance because they are among the lowest in cost and easiest to fabricate. Phenolics have good dimensional stability and high heat resistance, which make them useful for many applications. In packaging they most often are used for bottle caps. In fact, phenolics and another thermoset, urea-formaldehyde, once dominated the closure field. Now, thermoplastic PP, PEs, and PS have replaced much of the thermosets.

Chemistry

Phenol and formaldehyde are combined in the presence of an alkaline catalyst to form complicated and lattice-work molecules, which are difficult to define. In theory, the product of the reaction is dihydroxydiphenylmethane. Condensation is believed to occur through CH2 groups attached at the points marked with an asterisk (see Figure 8.7). There are three stages in the formation of the final product, known as the A, B, and C stages. The first reaction yields a low-molecular condensate; the intermediate phase gives a fusible, but insoluble material; and the final product is infusible and insoluble.

The properties of a phenolic depend to a large extent upon its filler material. Wood flour improves impact resistance and reduces shrinkage. Cotton flock imparts strength and rag fibers and clippings are still better. Asbestos and clays will enhance chemical resistance. A long list of other materials can be used for special purposes. Some are fine powders, others are crystalline or fibrous in nature.

Characteristics

There are different grades of phenolic molding compounds known as general-purpose, heat-resistant, impact, nonbleeding, and special-purpose. They are available only in dark colors, usually black or brown.

Phenolics are also hard, strong, and resistant to most chemicals. Phenolics

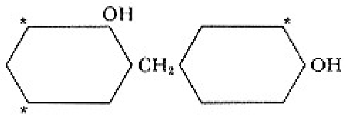

Figure 8.7.
Phenolic structure.

resist some dilute acids and alkalies, but are attacked by others, especially oxidizing acids. Organic acids and reducing acids do not usually have any effect. Strong alkalies will decompose phenolics. The bleed-proof type is generally resistant to all organic solvents. For details on phenolic properties and costs, see Table 8.2.

Advantages and Disadvantages

Low cost; rigidity; heat, chemical, and creep resistance; and strength are the outstanding properties of the phenolics. Color limitation is the chief drawback, although coatings and platings are available at a premium price. For bottle closures and fitments, the phenolics are an excellent choice. They can withstand torquing forces of the capping machines, and will maintain a tight seal over a long period of time without loosening. For more information on both thermoset and thermoplastic closures, see Chapter 13, Caps and Seals.

Applications

There are three methods of molding phenolics: compression, transfer, and injection. Today, injection molding is the favored process, particularly for small parts, and the machines are very similar to injection molders for thermoplastics. In thermoset molding, however, the molds are hot, whereas thermoplastic molds are cooled. It is claimed that injection molding produces more uniform parts at about 50 percent less cost than compression molding, and around 25 percent less than transfer molding for certain parts. Because mold and set-up costs are higher, injection molding is better suited to long runs. There are also limitations to the materials that can be injection-molded, because of a tendency for some to clog in the mold. Shrinkage factors are different for the different processes, too, and molds must be designed accordingly. Shrinkage for transfer molding, for instance, is greater than that for compression molding.

The oldest technique, compression molding, is slow and costly, but for small quantities may well be the most economical. This technique also can mold larger parts. With the transfer process, a preform is made and preheated. Gases are allowed to escape and the material is then put into the finishing mold. More heat is applied to make it "kick over" into the curing phase.

Polycarbonate

Dr. Daniel W. Fox discovered PC in the early 1950s while working for General Electric Co. (now GE Plastics, Pittsfield, Massachusetts). At about the same time the Farbenfabriken-Bayer AG of Germany also produced small quantities of this material. PC is a carbonic acid polyester of bisphenol A.

Chemistry

Amorphous PC is created by linking dihydric or polyhydric phenols through carbonate groups (see Figure 8.8). The general-purpose resin used in packaging is derived from bisphenol A. Branched PCs are used for blow molding and structural sheet. Special blends of PC with elastomers, polyolefins, thermoplastic polyesters, and ABS improve processability, lowtemperature toughness, and notch sensitivity.

Characteristics

PC has good clarity, outstanding impact strength, unusual ductility (more than 100 percent), and low, controllable mold shrinkage. PC is sterilizable and a special grade tolerates gamma radiation. It is a high-priced material, but for special applications it has exceptional mechanical properties and sometimes is substituted for metal. It absorbs moisture but does not swell significantly.

PC is resistant to dilute acids, oxidizing or reducing agents, salts, oils and greases, and aliphatic hydrocarbons. It is attacked by alkalies, amines, ketones, esters, aromatic hydrocarbons, chlorinated aliphatic hydrocarbons, and some alcohols. Dissolvable in methylene chloride, ethylene dichloride, dioxane, and cresol, the first two are useful for bonding PC parts: the first for small quick-setting joints; and a 50-50 mixture with the second for large areas and longer open times. Use the minimum of solvent, and heavy clamping pressure for at least 20 min.

For molding or extruding, PC must be absolutely dry, otherwise silvery streaks, splays, chicken tracks, or air bubbles may spoil its appearance. Even when the material is dry at the start, within 10 min. it can pick up enough moisture to affect production if it is not protected from the atmosphere. Not only will the finished piece not look as good, but the material will not have the toughness it should have, resulting in brittleness and failure under impact. Film is made by solvent casting or extrusion, the former giving better

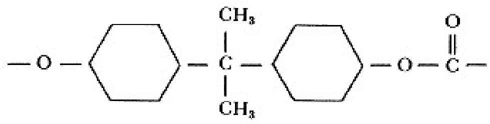

Figure 8.8
PC structure.

optical properties although at a higher cost. PC can be heated rapidly with little risk of thermal degradation.

For thermoforming, the sheet should be dried at 270 F (132 C) for at least 2 hr. Cold forming is possible and bending, stamping, cold heading, drawing, coining, and rolling have been done successfully. Cold rolling can be carried out with successive passes that create a reduction of 10 to 50 percent. Bending can be accomplished without heat by overbending. For a right-angle bend the amount of springback is about 15 .

Heat-sealing requires temperatures around 410 F (210 C) and can be done on thin sections with settings of 450 F (232 C) and 2 sec dwell time. Seal strength is around 1 lb/in. (178 g/cm). Dielectric sealing is not feasible because of the low power factor. Press welding of thick sections consists of heating the edges against a 660 F (349 C) hot plate for 3 to 4 sec and pressing them together. For properties and costs, see Table 8.2.

Advantages and Disadvantages

Use of PC in packaging has been very limited because of its high cost, but where great clarity, toughness, and a high softening temperature (270 F, 132 C) are required, it excels. It is also dimensionally stable and processable. Odorless and nonstaining, it is suitable for food packaging, but resistance to alkalies is poor.

Natural permeation of moisture and gases is high, and products sensitive to oxygen or carbon dioxide should not be packaged in plain PC containers for long storage. However, methods of coextruding PC film and sheet and co-injection molding with PVDC at temperatures close to 415 F (213 C), instead of PC's normal melting point of 500–550 F (260–288 C), have been created, thus enabling barrier film-wrapped packages and thermoforms.

Another technique for improving barrier properties in bottles is co-injection stretch blow molding with about one-third amorphous nylon. This European-made bottle is used as a returnable container.

Applications

One established usage for PC in packaging in the United States is reusable 5-gal water bottles. Light weight and shatter resistance are the chief advantages. Tray containers also are used in medical-device packaging and to a limited extent in dual-ovenable trays for foods. In these sheet-formed applications, PC's high-temperature resistance permits both autoclave sterilization and oven thawing and heating.

FDA Approval

Certain PC resins have been approved for use in molded and extruded constructions for food and medical packaging.

Polyester (Polyethylene Naphthalate)

Although most packagers have just heard of it, polyethylene naphthalate (PEN) has actually been around since the 1940s. No one's paid much attention to it because of its intrinsic high cost and the low yield from crude oil of its base material, dimethyl naphthalene. However, in 1993 Amoco Chemical Co., Chicago, created a synthetic base material, dimethyl-2,6-naphthalene dicarboxylate (NDC), which is made from widely available butadiene and oxylene. Amoco has also built a sizable production facility which will assure supplies and, thus, has sparked greater interest in the production of PEN/NDC from such other polymer producers as Eastman Chemical Co., Kingsport, Tennessee; DuPont Co., Wilmington, Delaware; Shell Polyester Business, Akron, Ohio; and Japan's Teijin.

Chemistry

Despite its name, PEN is more akin in manufacturing to PET than to PE. PEN is a thermoplastic, amorphous polyester and is the homopolymer of NDC and ethylene glycol. Existing methods for polymerizing dimethyl terephthalate (DMT) in the production of PET can be easily modified to produce PEN. The close resemblance between the PET and PEN molecules is shown in Figure 8.9.

Advantages and Disadvantages

Compared to PET, PEN's advantages are a significantly better moisture barrier; temperature resistance; strength; dimensional, thermal, and hydrolytic stability; and UV resistance. This is of great importance to bottlers of foods and beverages.

On the down side, PEN is currently much more expensive than PET, which is costly enough. PEN homopolymer currently is reported to be priced at \$3.25/lb (\$1.48/kg). At a density of 1.32, this yields a cost of \$0.16/in.^{3} (\$0.010/cm^3). However, if perhaps only a 90/10 percent mixture of PET and PEN are needed to boost PET's barrier properties, the mix would price out at about \$0.039/in.^{3} (\$0.0024/cm^3). Comparing this figure with other plastics in Table 8.2 would indicate that even at PEN's current costly stage, some niche markets such as hot-fill food applications may be possible. Like other plastics, though, the price of PEN will undoubtedly drop with volume and use.

So impressive are PEN's properties that relatively little reportedly is needed to boost PET performance for many applications. PEN can be blended with PET or copolymerized in either continuous or batch processes, enabling custom-made PET/PEN resins that can be practically manufactured in both large and small quantities to suit specific applications.

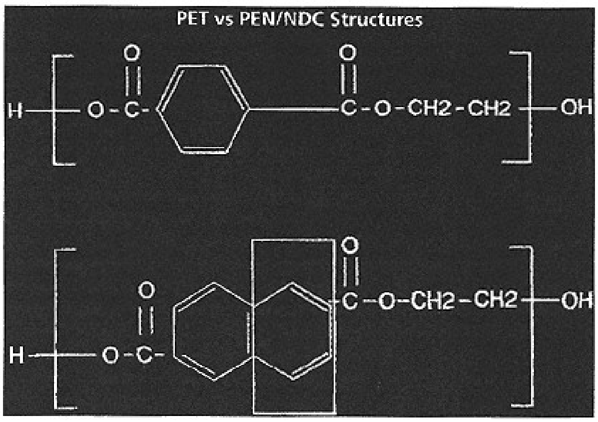

Figure 8.9.
PEN/PET structure.

Test containers of PET/PEN blends are reported to be on the market already in Europe, South America, and Japan.

Applications

PEN can prevent flavor and odor "scalping" (absorption into the container) in foods and increases the fill temperature of hot products to about 203 F (95 C). The barrier properties also interest beer bottlers, who are attracted to PEN's UV resistance and high oxygen barrier, both of which are requisites for this beverage. In addition to molded containers, PEN is also projected as a possible ingredient in films.

FDA Approval

No greater testimony to the hopes for this new material can be found than the fact that both NDC and PEN have received clearance for food-contact packaging in the United States and a number of other countries. Migration tests await PEN use in commercial U.S. applications. Environmentally, PEN does not pose a problem either. PET and PEN should blend into a random copolymer. If the use of pure PEN becomes economic, containers can be easily separated in waste sources because PEN fluoresces. Given the cost of this material, recycling is more than an option.

Polyester (Polyethylene Terephthalate)

Thermoplastic PET was created in 1941 by Calico Printers, a British company. Production rights were acquired by both DuPont and Imperial Chemical Industries, which then sold regional rights to many other companies. From its use as a major fiber in the textile industry, PET expanded into films and, in 1966, into molded and extruded parts.

When FDA revoked its interim approval of AN polymers for beverage containers, several companies started making PET bottles by an injection-stretch-blow-molding process, patented by DuPont in 1974. At first, PET bottles for carbonated drinks required a separate HDPE base cup to overcome the "rocker bottom" caused by the internal pressure. But then, Continental Group (now Continental Plastic Containers, Norwalk, Connecticut) patented a fluted-foot design that eliminates this extra piece. The design is not universally used, however, because the molds are more expensive, and the molding process is slower. Also, a 2-L bottle without a cup requires 70 g of PET, while 60 g is sufficient when a cup is used. The resultant costs are, therefore, nearly the same, but recycling of cupped bottles is a bit of a problem because the cup is made from a different material and, although recyclable itself, must be separated before reprocessing.

Specially prepared PET can be found in film and sheet, which increasingly is used in thermoformed ovenable trays. A copolyester, polyethylene terephthalate glycol (PETG), is used to injection-mold heavy-wall jars in both crystal-clear and translucent finishes, which look and feel like glass and have outstanding resistance to the oils and aromatics used in high-cost creams, lotions, and cosmetics. The containers also are easy to decorate with long-lasting inks, and gold and silver leaf. To prevent degradation, however, PETG must be dried before molding to less than 8 percent moisture content.

Chemistry

Thermoplastic APET is an amorphous, modified homopolymer created by the polycondensation of either purified terephthalic acid (PTA) or DMT with ethylene glycol (see Figure 8.9). Without further modifications, the melt is quenched in water to form amorphous and clear plastic pellets, which are further post-polymerized in the solid state for use in PET'S main products: textile fibers, films, and stretch-molded bottles of oriented PET. The ethylene is reacted to form glycols, which are capable of modifying the plastic to reduce crystallinity and melt temperature and increase melt strength.

On the other hand, accelerated crystallization, required for other plastic-forming packaging processes is achieved in crystallized PET (CPET) by including both inert and organic additives to speed nucleation in the plastic. Copolyesters are used for this purpose, as well.

Characteristics

PET excels in strength, toughness, and clarity. Filled 2-L bottles dropped on concrete from 6 ft have a survival rate above 97 percent. Originally, handleware was not possible with PET molded by stretch or injection blow molding. However, in the early 1990s, the problem was solved by development of a modified extrusion-blow-molding process and resin grade.

Although resistant to weak acids, bases, and most solvents, PET is not a great barrier for gases. As a result, shelf life for carbonated beverages is only 8 weeks in 0.5-L bottles and 12 weeks for 1-L, a minimum for industry distribution. PET is not suitable for beer or wine because of its permeability to oxygen. (As little as 1 cc of oxygen is enough to spoil the flavor of most beers.) However, miniature PET bottles are being used for liquor, particularly for airline service, and a few spirits have converted to lightweight PET in standard sizes because of the shipping advantages. For more details on properties and cost, see Table 8.2.

PET film is growing in usage because of its strength. Tensile strength of unoriented PET is 6,200 to 9,200 psi (42.8 to 63.4 MPa); of oriented PET, 32,000 to 39,000 psi (220.6 to 268.9 MPa). Biaxial orientation creates a very stable film and laminations and coatings add to the barrier properties. Blending PET with special nylons also increases barrier properties and strength (see Nylon, page 233). For other properties and cost, see Tables 3.1 and 3.5 in Chapter 3, Films and Foils and Chapter 4, Coatings and Laminations.

Advantages and Disadvantages

Polyester is a fairly stiff material and when bottles of carbonated beverages are pressurized, the wall thickness needs to be only 0.010 to 0.015 in. (0.25 to 0.38 mm). This decreases costs, because without this internal pressure, the walls would have to be 0.025 to 0.030 in. (0.64 to 0.76 mm) thick. Bottle weight, varies by a few grams from application to application depending on the product and bottlers' needs for carbonation retention and top-loading strength.

For beverages that are distributed regionally, the weight savings over glass containers may not be significant, but for edible oils, fruit juices, and other products that are shipped across the country, this factor can mean significant savings.

Applications

Films and sheet for thermoforming are cast and thermoforms are crystallized to heat-set the trays. Copolymers can be added to extrusion-blow-molding and film grades to improve melt strength. PET resins must be dried before processing.

FDA Approval

Most PET resins are in compliance with CFR 21 177.1632 for repeated food contact applications.

Polyethylene, High Density

In the mid-1950s, independent investigators almost simultaneously created HDPE with low-pressure processes, a thermoplastic that has turned out to be one of the most versatile and successful in the packaging field.

Prof. Karl Ziegler of Germany used a metal halide/aluminum alkyl catalyst. Researchers at Phillips Petroleum Co. used chromium oxide on a silica base. These catalysts became the basis for production of HDPE by two processes that can produce either an ethylene homopolymer or copolymers incorporating butene, hexene, or octene.

Of the 32.3 billion lb (14.7 billion kg) of PE produced in the United States about 37 percent (11.9 billion lb, 5.4 billion kg) is the high-density type [5]. About 18 percent (5.8 billion lb, 2.6 billion kg) of this is used for packaging, divided among blow molding, 60 percent; injection molding, 34.5 percent;and film/sheet, 5.5 percent[6].

Chemistry

The molecular structure of HDPE is essentially the same as for the lowdensity material, with this main difference: There are relatively few side branches, so the molecules are permitted to line up nearly parallel and close together (see Figure 8.4). Thus, crystallinity can range up to 95 percent, providing a relatively hard, stiff, and impermeable material.

Characteristics

This low-cost, moderately flexible plastic is used to a large extent for blow-molded bottles. It is stiffer and has much better barrier properties than LDPE (see Table 8.2). Chemical resistance is good and can be improved for use with aliphatic hydrocarbons, alcohols, ketones, and some acids and bases by such internal surface treatments as sulfonation or fluorination or by blending with higher barrier plastics such as nylon. Clarity is poor except in cast films, where rapid chilling reduces crystal formation. HDPE is translucent in its natural state and can be tinted with any opaque color. It is also essentially tasteless and odorless. For more details on properties and costs, see Table 8.2.

Advantages and Disadvantages

The relative low density and cost/pound make this one of the most useful of plastics for packaging a wide range of products, including foods and household chemicals. It is a good barrier for moisture, but relatively poor for oxygen and other gases. Odors and flavors are sometimes lost differentially, as with LDPE. That is, certain fractions of a perfume or flavoring oil can transpire more rapidly than others, leaving an odd taste or smell, which is undesirable. Outward permeation of product gases or liquids also can cause HDPE bottles to distort or "collapse." This reaction can be minimized or concealed with proper bottle design.

Most solvents will not attack HDPE and it is unaffected by strong acids and alkalies, with the possible exception of hot concentrated nitric acid. It will stresscrack in the presence of some products such as detergents, unless it is formulated with other resins that minimize this tendency. The addition of small amounts of butene, hexene, or octene can modify and improve many HDPE properties. The use of different catalysts also have a marked effect on properties.

The higher the density, the stiffer the material, which means that a thinner wall section can be used. By substituting HDPE for LDPE, container weight can be reduced 40 percent or more without affecting rigidity, based on a comparison of tensile moduli. Increases in density also tend to lower stress cracking, a positive factor in the use of relatively new high-molecular-weight (HMW) HDPEs and ultra-HMW PEs.

The surface of HDPE is nonpolar and therefore must be exposed to a flame, corona, or gas treatment before printing or applying adhesives (see Figures 3.9, 3.10, and 3.11 in Chapter 3, Films and Foils).

Applications

Because of HDPE's stiffness, as compared with LDPE, the former is preferred for thin-wall blow-molded containers. Injection molding of closures and similar parts is fairly common, and rotational molding is used for large containers such as carboys.

HDPE also is extruded into tubing, film, and sheet for applications where transparency is not essential such as industrial and consumer bags and thermoformed trays. HMW HDPEs are growing in use for industrial container liners and bags, while UHMW PEs are finding their way into extra-tough and self-lubricating conveyor rollers and timing augers.

FDA Approval

HDPE itself is acceptable for use in packaging food and drug products. However, a number of its additives do not comply so such agents must be selected with care.

Polyethylene, Linear Low Density

In recent years, development of low-pressure production methods has resulted in creation of LLDPE. Although made by DuPont via a solution process in Canada in 1960, large markets developed only in the late 1970s with the introduction by Union Carbide Corp., Danbury, Connecticut, of a gas-phase polymerization process. An advantage of this low-pressure system is that reactors can be switched from LLDPE to HDPE production as marketing needs vary. U.S. use of this versatile plastic in packaging in 1995 was 2.8 billion lb (1.3 billion kg) [7]. The world market in 1995 was about 22 billion lb (10 billion kg).

Chemistry

LLDPE has no long branches and its density can be controlled with the addition of comonomers. It differs structurally from LDPE since it is a copolymer of ethylene with the addition of such higher olefins as butylene, hexene, or octene. The result is a plastic with a narrower MWD, a more linear structure, and a melt flow that has necessitated new extrusion techniques to produce a workable film. It is expected that metallocene technology will further enhance the properties of this useful plastic.

Characteristics

Low cost, light weight, superior toughness, rigidity, flexibility, moisture barrier, chemical and stress-crack resistance has made LLDPE a replacement for LDPE in many film and injection-molded part applications as well as opened new packaging and nonpackaging markets for PE. About 373 million lb (169 million kg) are currently used in U.S. packaging films with continued growth expected [8]. However, LLDPE is not as transparent as LDPE, which has a lower haze level. For more information on properties and costs, see Table 8.2.

Advantages and Disadvantages

The advantages of LLDPE are its good tensile strength, puncture resistance, impact and tear properties, low-temperature impact and, most of all, its outstanding resistance to stress cracking and warping.

Applications

Stiffer than LDPE, it is ideal for large-sized bagging and wrapping operations where great strength and resistance to physical damage are primary. LLDPE can be processed in the same ways as its relative, but because it has shorter chains, is less prone to strain hardening. This allows LLDPE to be downgauged easily while still retaining a high degree of strength and toughness. Extrusion equipment differs with LLDPE because it requires more power and pressures due to its higher viscosity. More sophisticated double lip air rings are required to blow LLDPE, as well, because the bubble is not as stable as with LDPE. Blends of LDPE and LLDPE, though, process very well on standard equipment in up to 50/50 mixtures.

FDA Approval

LLDPEs have food-contact approval with the same caveat as for LDPE: Any additives must also be food approved.

Polyethylene, Low Density

Developed by M. W. Perrin and J. C. Swallow of Imperial Chemical Industries Ltd. (ICI) in England during the early 1930s, PE reached commercial importance during World War II as a protective coating. In 1939 ICI licensed DuPont to produce PE for wire and cable insulation. Union Carbide developed its own methods for making PE in 1940, followed by I. G. Farbenindustrie in Germany in 1942.

About 8.3 billion lb (3.8 billion kg) of LDPE was produced in the United States in 1995, of which about 740 million lb (335.7 million kg) was used for packaging films and 920 million lb (417.3 million kg) for injection, blow, and rotational molding [9]. The world market in 1995 was about 29 billion lb (13.2 billion kg).

After a dip in usage following the introduction of LLDPE some years ago, LDPE is regaining packaging markets, particularly with the advent of new HMW resins for improved packaging films (see Chapter 3, Films and Foils) and a market for the newer ultra-low-density polyethylenes (ULDPE) also called very-low-density polyethylenes (VLDPE), which have enhanced properties. PE foam has had a steady market for high-quality cushioning.

Chemistry

LDPE is made from ethylene gas under high pressure (around 50,000 psi, 345 MPa) and temperature (about 300 F, 149 C). Small amounts of organic peroxide are used as a catalyst. LDPE is essentially a straight-chain compound with long side branches that give it its flexibility of properties and ease of processing (see Figure 8.10). Excessive branching, however, interferes with close packing of the molecules and results in a soft, greasy material. Less branching allows the molecules to pack together and produce a combination of crystalline and amorphous regions that are stiffer, denser, and less permeable (see Figure 8.11).

New metallocene catalysts (see page 212) are said to create even better strength and toughness, sealability, barrier properties, and clarity. But metallocene polyethylene (mPE) also is more expensive at this time and still can be difficult to process.

Enhanced properties are the reasons for the new ULDPEs that, like LLDPE, are copolymers of ethylene with butene-1, octene-1, hexene-1, 4-methyl-pentene-l, or combinations of these monomers. Typically, these

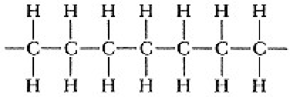

Figure 8.10.
LDPE structure.

narrow-range MWD PEs have increased strength and flexibility; clarity; puncture, tear and impact resistance; and a broader and lower heat-sealing range. A lower degree of crystallinity increases permeability to gases and reduces moisture permeability, increases chemical resistance, and adds thermal stability. They blend with such heavy-duty films as HDPE and boost its properties. ULDPEs can be coextruded with other PEs and PP.

There are now dozens of different grades of LDPE. Variations are due to the different lengths of the molecules (not only the greatest length but the proportions of different lengths) and to the amount of branching and cross-linking. As an example, a recent generation of low-cost VLDPEs has been introduced to packaging for use as adhesives, coatings, and film applications such as trash bags. This constant change in properties and cost relationships is a solid reason why packaging technologists should read plastics publications to keep themselves up-to-date on such competitive innovations.

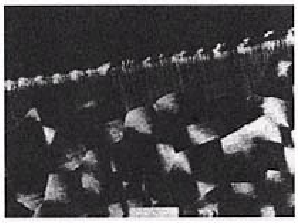

Figure 8.11.
Long-chain PE molecules form dendritic (branched) crystals, which are folded back every 100 Å or so, making lamellae that are about 150 layers thick. Chilling of the surface causes spherulites to nucleate very close together. The lamellae, which grow from these nuclei, propagate perpendicular to the surface, since they are restricted by neighboring spherulites. This forms a transcrystalline region, which is about 15 m (0.0006 in.) thick. (Source: Journal of Applied Physics, used with permission.)

Characteristics

LDPE is nearly odorless and tasteless for most applications, but should be carefully tested when used with foods. It is easily blended with such copolymers as ethylene methacrylic acid (EMA), ethylene-vinyl acetate (EVA), ethylene normal butyl acrylate (EnBA), ionomers, and ethylene-ethyl-acrylate (EEA) to further extend and improve its properties.

LDPE is highly resistant to most solvents, but at temperatures above 140 F (60 C) is attacked by some aromatic hydrocarbons. Certain oils and greases, such as mineral oil, can permeate LDPE film or containers to coat the outside, making it necessary to test compounds before using it with these types of products. LDPE is unaffected by acids and alkalies, with the exception of hot concentrated nitric acid. However, permeation and weight loss of liquids through PE containers is quite variable, thus creating a use for LLDPE.

LDPE is a poor barrier for gases (see Table 8.2) and, therefore, odor and flavor essences are sometimes lost through container walls. Some fractions move out faster than others, often creating odd results.

Softening temperature of this plastic is around 210 F (99 C). It is a good dielectric, but this makes it difficult to seal on dielectric equipment because of the large amount of power required.

LDPE can have good transparency in thin sections, but cannot be made crystal clear. In thick-walled containers it is translucent and waxy in appearance. Easily pigmented, any opaque color can be used in bottle resins, but such metallic colors as gold, silver, and bronze do not show very good brilliance. The surface of LDPE is nonpolar, so it is difficult to get adhesives or inks to adhere. Treatment with flame or corona discharge is necessary before it can be printed. For more information on properties and costs, see Table 8.2.

Advantages and Disadvantages

The flexibility, moisture protection, toughness, chemical resistance, light weight, and low cost of LDPE are its most outstanding attributes. However, it is not practical for many rigid containers and flexible packages can be difficult to open because of the way the film stretches without tearing. Flavor and odor problems can be more prevalent than with PP.

Stress cracking can be a problem in the presence of certain chemicals such as detergents. This is why many applications requiring chemical and stress-crack resistance have migrated to LLDPE film containers and molded packaging components. LDPE is also prone to "lacing" when pigmented with titanium dioxide. This can cause thinning ("lensing") or even lacy holes in the film. The cause is a boiling off of low molecular weight elements at the die exit. The solution is oven drying of the concentrate, which should not be allowed to age or pick up moisture. High temperatures also increase the probability of lacing.

PEs are not recommended for oily products, which may pass through the walls and make the outside sticky to the touch. A poor barrier to gases, LDPE should not be used with products that are sensitive to oxygen. It also has a strong tendency to develop a static charge that attracts dust, which can be unsightly on a retail shelf.

Applications

LDPE is produced in many forms, such as sheet, film, coatings, extrusions, and moldings. In rigid containers, it is used in squeezable tubes and bottles where its flexibility supplies a dispensing function.

LDPE films are in wide use for a great range of products. Softness, toughness, and low cost make it useful for wrappers and bags for products ranging from fresh produce, baked goods, and frozen foods to chemicals, hardware, and garments. Film is made by casting onto a chilled roll or by extrusion as a tube or flat film. In tubular extrusion, air pressure inflates the bubble and orients the molecules, making a tougher film. Tubing is usually extruded upward, although it can be made downward when it is desired to quench it in a water bath to improve transparency.

A relatively small amount of sheet is thermoformed into trays. Sheet material is being thermoformed for margarine tubs and frozen food containers, among other things. LDPE is very heat sealable by both hot-wire cut-off and Teflon-coated bar sealers.

LDPE is a preeminent material for extrusion coating, either alone or combined with some of the polymers mentioned above. As a coating material it is used on butter cartons, bacon wrappers, and paperboard milk containers.

PE foam is available in both extruded and, more recently, expandable form (EPE). It is a low-density, closed-cell, weather-stable cushioning that is soft and nonabrasive. The expandable form is available in "planks" like the extruded variety and a moldable version. There is also an expandable PE copolymer (EPC) (see Chapter 16, Cushioning for more information on this cushioning material).

FDA Approval

All PEs are acceptable for packaging food and drug products, provided that no unacceptable additives or mold-release agents are used in the manufacturing processes.

Polypropylene

PP was first created in 1954 by Prof. Giulio Natta of the Milan Polytechnic Institute and quickly became the fastest growing commodity plastic in the world, exceeded in total usage only by PE and PVC. About 2.6 billion lb (1.2

billion kg) of PP was used in packaging in the United States in 1995 out of a national total of 10.6 billion lb (4.8 billion kg) [10]. About 50 percent is used for oriented and unoriented film. The rest is split between blow- and injection-molded containers and sheet for thermoforming [11].

Chemistry

PP is a very long-chain homopolymer similar to PE, but more complex. It has two forms. The stereoregular form is created by connection of basic molecules head to tail. The head end of the molecule has three hydrogen atoms, as shown in Figure 8.12.

For this form, Prof. Natta coined the word *isotactic* and the polymer is crystalline (see Figure 8.13). However, in the process, some molecules are randomly attached to each other, forming a soft and sticky atactic PP. It is amorphous and degrades when exposed to oxygen and light without preventive additives. Commercial PP usually contains about 5 percent of the atactic form. The crystalline form is what gives PP its stiffness and heat and chemical resistance.

PP is sold in three basic forms: homopolymer, random copolymer, and block copolymer. These forms have a range of stiffness, toughness, and impact resistance to suit various end uses. For example, ethylene is added to PP in a secondary reactor polymerization to form random copolymers that improve impact strength and lower the melting point. Recently, a butene copolymer has been developed to optimize the balance of properties in both cast and biaxially oriented PP films. Still another generation of new PP copolymers is resulting from use of a gas-phase polymerization process that may enable PP to compete with PET in some injection-molding applications.

Block copolymers are thermoplastic elastomers (TPEs), which have gained enormously in usage since their introduction in the 1960s. The first were styrene-dienes followed by copolyesters, polyurethanes, and polyamides. They also include TPOs or thermoplastic polyolefin/elastomer blends. TPEs are fully compounded and ready to use and consist of a hard thermoplastic phase and a soft elastomeric phase. Resultant properties are those of the two phases as well as their interaction. In a block copolymer, the hard and soft phases alternate on a polymer chain in consecutive "blocks."

An example is the styrene-diene block copolymer with the structure

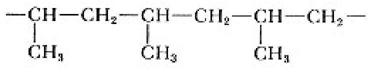

Figure 8.12
PP structure.

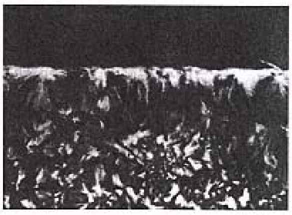

Figure 8.13.
Rapid cooling of PP produces large numbers of small spherulites, improving the transparency of thin films. These spherulites grow perpendicular to the surface because they are limited by adjacent spherulites from going in any other direction. This causes a transcrystalline region at the surface about 12 m (0.0005 in.) thick, which can be seen in the microphotograph. (Source: Journal of Applied Physics, used with permission.)

—S—D—S—, in which the S is the hard styrene or styrene derivative and D is the soft and rubbery diene element, which commonly consists of polybutadiene, polyisoprene, or polyethylene-butylene.

Properties such as flexibility and other important characteristics can be changed by varying the proportion of hard and soft blocks, which perform entirely differently than if the compound was an ordinary random copolymer of the same basic monomers, styrene-butadiene, for example.

PP is also subject to modification by use of the new metallocene catalyst that, in principle, is reportedly capable of changing each property independently from the others, including the content of atatic PP. First grades will be improved homopolymers followed by copolymers with enhanced hardness and impact strength. Injection-molding grades will be aimed at thinner wall structures with greater stiffness, gloss, and thermal resistance.

Because PP crystallizes rather slowly, it forms large spherulites, which scatter light. To improve clarity, these must be reduced in size. Since the 1970s, this has been accomplished with sorbitol-based clarifying agents, introduced by the Japanese and now used around the world to improve the clarity and organoleptic properties of PP. Modifications of these sorbitol agents is still going forward with a new third-generation additive that further improves both clarity and organoleptics at lower concentrations.

Characteristics

Perhaps more than any other thermoplastic, PP has an unequaled balance of electrical properties, heat and chemical resistance, toughness, rigidity, dimensional stability, surface gloss, and melt flow. PP has good resistance to strong acids and alkalies, and is unaffected by most solvents at room temperature, except for chlorinated hydrocarbons. At elevated temperatures benzene, xylene, toluene, and turpentine are unsatisfactory, and strong nitric acid will react. PP resists oils and greases, and it does not stress-crack under any condition. It is a fairly good barrier to moisture and gases. For printing or attachment with adhesives, it must be flame-treated because the surface is nonpolar.

The density of PP at 0.900–0.915 makes it among the lightest of all plastics and, therefore, results in a very high yield per pound. It is not transparent except in film form, which can be made crystal clear by rapid chilling or, in the slower chilled materials that form crystalline spherulites, by reducing the size of these with the addition of one of several nucleating agents. To improve PP properties, random copolymerization with ethylene, butene, or a terpolymer of all three can be constructed. Ethylene and butene are said to optimize PP properties.

The material has a relatively high melting point, good strength, and can be copolymerized or “filled” with lower cost, inert substances such as glass fibre, mica, talc, and calcium carbonate for molding and as carriers for pigments in both molding and extrusion. A unique property of PP is its almost infinite resistance to flex-fatigue even in very thin sections. This enables the injection molding of “living hinges” into dispensing closures and boxes.

One of the greatest shortcomings of PP, however, is its brittleness at low temperatures. In its purest form, it is quite fragile around 0 F (-17 C) and must be blended with other monomers such as PE or copolymers to give it the impact resistance required for packages distributed or used at low temperatures. For more details on properties and costs, see Table 8.2.

Advantages and Disadvantages

Light weight and low cost per pound make PP a very useful plastic for packaging purposes. A major advantage of PP in molding is that its shrinkage is less that of any other polyolefin, making it more predictable and less likely to cause warpage in flat panels.

While impact strength of pure PP is not very good, it can be improved greatly by adding impact copolymers containing a high degree of ethylene. Such additives also widen PP's rather sharp melting point, which made heat sealing difficult in the early days. The additives also reduce PP film's tendency to form hair-like threads (“angel hairs”) in sealing.

The sharp melting point also prevented PP sheet from being used in thermoformed containers at first. However, additives and fillers again have spread this sharp hot zone and additional modifications in the thermal devices used to heat the sheet have resulted in PP being increasingly employed in thermoformed trays, particularly for food.

Applications

PP can be thermoformed, blow molded, injection molded, and extruded. It is widely used in closures of all kinds and, because of its resilience, can be designed as "linerless" (see Chapter 13, Closures). Its high melting point makes it suitable for some boil-in-bag packages and for containers used with sterilized products. PP also is used in selected bottle applications, particularly for aggressive products that stress-crack other polyolefins and for hotfilling. As with the PEs, PP is also a standard plastic in molded containers for industrial products.

FDA Approval

There are many types of PP that meet regulations for food-contact use, provided additives or mold release agents that do not comply are avoided.

Polyvinyl Chloride

Sometimes called simply vinyl, PVC was introduced commercially in 1927, but not broadly used until World War II, where it substituted for scarce natural rubber. It can be used as a rigid material or plasticized to a soft flexible sheet.

Annual U.S. production is more than 128 billion lb (58.1 billion kg) [12]. So useful is this material in both packaging and other markets that, despite some concern by environmentalists over its chlorine content, growth of PVC is expected to outpace that of the world economy for the next few years.

The majority of U.S. output goes into building and construction, although markets in home and office furnishings, agricultural piping, and transportation are also large. Only 743 million lb (337 million kg) in the United States becomes packaging in the forms of bottles, film, and sheet [13].

PVC homopolymer alone is a very difficult resin to process, but the addition of many plasticizers, lubricants, impact modifiers, fillers, and pigments have created a host of useful packaging forms and applications. Competition from the metallocene-based polyolefins (see the PE section above) may well be driven by their capability to supply many PVC properties without the use of plasticizers, which tend to migrate out of PVC.

Chemistry

Vinyl chloride monomer gas is formed from ethylene, obtained from petroleum, and chlorine, obtained from sodium-chloride brine. Polymerization creates PVC, a white powder, the structure of which is shown in Figure 8.14.

PVC can be made by four different exothermic processes of suspension-, mass-, emulsion- and solution-polymerization that produce resins with very different structures (morphologies). However, the suspension process is

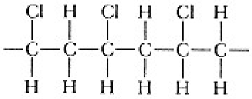

Figure 8.14.
PVC structure.

used for more than 90 percent of the output and can deliver either rigid, nonplasticized or flexible plasticized resins. Although PVC containers and films have been broadly used for food products, FDA became concerned in the 1970s about the level of vinyl-chloride monomer gas in the plastic. Industry voluntarily worked out processes that, today, insure a typical residual level of the monomer (which does not have food approval) to less than 1 ppm.

To be useful, PVC must incorporate a number of additives. For example, all PVCs are temperature sensitive and require an organometallic heat stabilizer to prevent deterioration from oxidation, formation of hydrogen chloride, and further degradation in use from heat and light.

A variety of plasticizers, usually high-boiling-point solvents, are combined with PVC to produce various degrees of low-temperature flexibility, resistance to migration of the additives, and additional heat stability. Lubricants reduce surface friction and static. Impact modifiers boost strength. Countless other flame retardants, slip and antiblocking agents, colorants, and blowing agents also are employed. Molecular weights range from 0.50 to 1.20 with both tear and tensile strengths higher at the upper range, but at a cost of more difficult processing.

Normally, plasticizers are used in both flexible and rigid PVCs. However, to offset packaging problems with migrating plasticizers, an Italian process of customized resin formulations and a special extrusion blowing process has produced a line of nonplasticized PVC films of particular usefulness in food packaging.

Characteristics

In its natural state, PVC is crystal clear and low in impact strength. The plastic has a specific gravity of 1.40, but its bulk density is far less since the molecule has a great deal of void (porosity), which helps it absorb all of the additives typically blended with it. The material is tough and has good puncture resistance and credible barrier properties. PVC films have strong cling and the resin is a good film former and can be molded with ease.

PVC is an excellent barrier for oils, alcohols, and petroleum solvents, but any plasticizer will be extracted by solvents. This action usually leaves the plastic hard and stiff, but sometimes the effect is not immediately apparent, because the product solvent either softens the plastic or replaces the plasticizer. Later, when the solvent evaporates, the full effect is realized.

PVC retains odors and flavors quite well. Rigid PVC is a fairly good barrier for moisture and gases in general, but plasticizers will reduce these properties. It is affected by aromatic hydrocarbons, halogenated hydrocarbons, ketones, aldehydes, esters, aromatic ethers, anhydrides, and molecules containing nitrogen, sulfur, or phosphorus. Water loss from a 4-oz bottle is about 2 percent/year. PVC is not affected by acids or alkalies, except some oxidizing acids, but the plasticizers may be hydrolyzed by concentrated acids and alkalies. Oxidizing and reducing agents have no effect, nor does chlorine. Impact resistance of PVC is poor, especially at low temperatures. For more details on properties and costs, see Table 8.2.

Advantages and Disadvantages

PVC is a relatively inexpensive, tough, clear material that with appropriate additives is easily processed. It must not be overheated, however, as it starts to degrade at about 280 F (137.8 C) and the degradation products are very corrosive. PVC yellows when exposed to heat or UV light unless guarded with a stabilizer. As with any transparent plastic, scratches will show up badly if it is abused in production or shipment.

Applications

Most food applications are served by thermoforms and lid structures made from extruded rigid and semirigid sheet. PVC thermoforms very well. Extrusion-blown PVC film has a major market in film wraps for meat and produce (see Chapter 3, Films and Foils). Although challenged by LLDPE, oriented PVC film retains some garment, box, and pallet-load wrapping applications. Rigid PVC is readily blow-, injection- and stretch-molded, which has led to markets in nonfood bottle applications for toiletries and cosmetics, household chemicals, and oils.

Blister packaging for pharmaceutical tablets and capsules is an application for which PVC has no real competition. Though PS and PET sheets compete in other thermoformed packaging applications, PVC still retains a strong position for hardware items.

FDA Approval

PVC is approved for use in food-contact applications, provided that unacceptable materials are not incorporated as plasticizers, stabilizers, or other additives.

In the 1970s, use of PVC bottles for liquors had just been approved by the Bureau of Alcohol, Tobacco and Firearms (ATF), when there were reports of 10 to 20 ppm of residual vinyl chloride monomer in the resin and cases of a rare liver cancer among workers exposed to the monomer in vinyl plants. ATF canceled its PVC approval, and FDA drafted a ban on the use of PVC in food packaging, which was never implemented. Plastics manufacturers subsequently revised manufacturing procedures and reduced the monomer content to less than 1 ppm. PVC has not regained acceptance, however, in liquor packaging which has opted for PET in some airline bottles.

Styrenics (Acrylonitrile-Butadiene-Styrene and Styrene-Acrylonitrile)

Two of the more successful combinations of copolymerized plastics has been the terpolymer ABS (acrylonitrile-butadiene-styrene) and the copolymer SAN (styrene-acrylonitrile), both of which are engineering plastics that are not used extensively in packaging, except where more toughness, rigidity, and chemical resistance is required than can be supplied by general-purpose polystyrene (GPPS).

Chemistry

The three constituents of ABS have the basic structures shown in Figure 8.15. SAN is a copolymer with the AN structure shown in Figure 8.5. Usually, ABS is created by grafting SAN to butadiene rubber. However, both plastics can be made by copolymerization of the individual constituents. Emphasis will be placed on ABS properties, since SAN is rarely used alone in packaging.

The proportions of the different constituents from which copolymers and terpolymers are made can vary and the chemical and physical properties will differ accordingly. In the case of ABS, for example, as AN content increases, so does chemical resistance and heat stability; more butadiene boosts toughness and impact strength, but decreases tensile strength; more styrene improves rigidity and processability. Varying these monomers creates a whole family of polymers, such as SAN, which features resistance to warpage and high impact strength.

Both plastics also have a broad capability of alloying with a number of

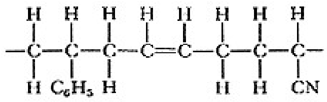

Figure 8.15.
ABS, a terpolymer, is made up of these three constituents.

other plastics; ABS with the crystalline polymer polybutylene terephthalate and nylon, for example, which boost the chemical resistance of the material in such applications as cosmetic and toiletry packaging; SAN with PC and PVC for addition of such functional properties as processability and strength, respectively. The ABS molecular chain may have a regular pattern, but is more likely to have a random configuration, as seen in Figure 8.5. Plasticizers are almost never used with ABS, as there is no need for them.

Characteristics

While usually thought of as an engineering material for things like automobile parts, ABS has limited use in packaging applications. A translucent thermoplastic of exceptional toughness and medium cost, ABS has a slight yellowish cast and glossy surface finish. Because it has good hardness and stiffness, thin-wall containers can be made from it.

ABS is highly resistant to scuffing, marring, and staining. Impact strength is equal to or better than that of impact styrene and in a falling-dart test, it is exceeded only by nylon and PE. In tensile and flex strength, only nylon and acetal are better among the common plastics. Cold flow under load is minimal, even at elevated temperatures.

Chemical resistance of terpolymers is not as good as for the components separately, and ABS is no exception. It is soluble in ketones, aldehydes, esters, and some chlorinated hydrocarbons. It is resistant to some hydrocarbons, but others cause softening and swelling. Some chemicals, which ordinarily do not affect ABS may, under load, cause stress cracking. This can happen with some alcohols, oils, or greases. ABS is resistant to alkalies and weak acids, but is attacked by strong acids. For further information on properties and costs, see Table 8.2.

Advantages and Disadvantages

Impact resistance and toughness are the chief advantages of ABS. It is not transparent and a true white is not possible because of the yellowish color of the base resin. The surface finish is glossy but not as sparkling as, for example, PS. Cost is relatively high for packaging, but stiffness and light weight permit the use of less material than is the case with some lower priced resins. However, in packaging, this material can expect to find continued competition from such lower cost plastics as PP and high-impact polystyrene (HIPS).

Applications

ABS and SAN generally are injection molded or extruded, although they also can be calendered, blow molded, and thermoformed. It is necessary to pre-dry ABS before processing. Injection molding is rapid and easy at 400–500 F (204–260 C) and 10,000–20,000 psi (69–138 MPa) with no mold release agents needed, no degradation of the resin, and very little warpage. ABS accepts decoration readily without any surface preparation.

FDA Approval

Food contact is permitted by FDA if this material is made according to regulations and does not contain unapproved additives.

Styrenics (Polystyrene)

A material called "styrol" was synthesized by E. Simon in 1839, but was not used commercially until 1925, when I. G. Farbenindustrie of Germany introduced it as an intermediate in the manufacture of synthetic rubber. PS was first produced as a plastic in this country in the 1930s, and despite the growth of other plastics, it still is a major factor in packaging.

Packaging consumed 1.5 billion lb (680 million kg) in 1995, with significant usage in cups and lids, rigid molded containers, closures, and expandable-bead foam cushioning [14]. The grades are crystal, high impact, high heat, flame retardant and a partially processed expandable bead (EPS). The impact grade can be further characterized as rubber-modified medium or high-impact polystyrene (MIPS or HIPS), which are generally translucent or opaque. GPPS is the major styrenic, but others also are used in packaging (see ABS and styrene-butadiene copolymer descriptions in this section).

Chemistry

PS is formed by reacting benzene with ethylene gas to form ethylbenzene, which is then dehydrogenated to create the styrene monomer, which is joined together in long chains to form the polymer, as shown in Figure 8.16.

For EPS, small granules of PS are impregnated with a hydrocarbon (pentane) blowing agent that, when heated to 185 to 205 F (85 to 96 C), creates partially expanded beads that are then foamed to final shape in steam-heated molds. There is also a foamed cushioning made from SAN. For additional information on this foamed plastic, see Chapter 16, Cushioning.

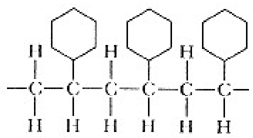

Figure 8.16.
PS structure.

Characteristics

GPPS is crystal clear and very hard, brittle, and rigid. The surface finish is excellent, and it has a brilliance without equal among plastics. However, PS is attacked by many chemicals which cause it to craze and crack, and so it generally is used only with dry products.

However, a recent innovation is the addition of polyphenylene ether (PPE), also known as polyphenylene oxide (PPO), which creates dramatic improvements in heat resistance, toughness, resistance to environmental stress cracking, tensile strength, tensile elongation, flex strength, modulus melt flow, and ductility.

PPE is an engineering plastic alloy developed in the 1960s by Dr. Alan Hay of General Electric and now used in combination with HIPS and nylon in packaging applications. Mixtures of PPE with HIPS are fully miscible and the above improvements in properties are linear in direct proportion to the amount of added PPE. In engineering applications, PPE has been added in quantities to 35 percent, but it is found that relatively low loading of 25 percent or less created significant improvements in sheet-formed containers for food and medical applications. Similar improvements are shown in mixtures of PPE to create low-density foamed sheet, too.

PS has a low melting point (190 F, 88 C) and cannot be used for hot foods or other high-temperature applications. Elongation under stress is nil, and therefore impact strength is poor. Styrene is resistant to acids and alkalies, except strong oxidizing acids. It is not affected by the lower alcohols or glycols, but is attacked by higher alcohols, esters, ketones, and aromatic and chlorinated hydrocarbons. PS is not a good barrier for moisture or gases. It is odorless and tasteless and can be used with foods.

Many of the disadvantages of GPPS are overcome by combining it with other materials such as SAN, styrene maleic anhydride (SMA), and other styrene-acrylic copolymers and rubber compounds. Although clarity is sacrificed in most cases, the resulting copolymer has greatly improved mechanical properties. Styrene sheet and moldings also have been combined with extruded or coextruded coatings of such barrier materials as PVDC and EVOH to give an otherwise low-cost material high-tech barrier properties.

Technical innovations in process design have enabled production of foamed PS sheet with a high molecular weight and high-temperature resistance and residual volatiles levels below 200 ppm for applications where low odor and taste properties are essential. For more details on properties and costs, see Table 8.2.

Advantages and Disadvantages

The crystal-clearness and light weight of PS make it very useful for the display packaging of products that benefit by full viewing. Low in cost, it is easily molded, thermoformed, and extruded into film. The material accepts printing, metallizing, and hot-stamping very well.

On the down side, PS has a slight tendency to shrink with age and will discolor in strong sunlight. When in contact with some solvents, or even their fumes, it will craze and become cloudy. If it is placed against other plastics, notably vinyl, it may absorb the plasticizers and discolor. PS builds up static charges easily and, thus, has a great affinity for collecting dust on its surface.

Applications

PS thermoforms well and is used for egg cartons, rigid disposable and reusable boxes, and food cups and trays. Because the film is very permeable, it has been used as container covers and wraps for fresh fruits and vegetables. Film usually is oriented to increase impact strength.

For bottles for pharmaceutical tablets and capsules, the material can be injection or blow molded. PS works easily in injection molds and has a low shrinkage rate, so that there is very little warpage and few sink marks. For blow molding, it is necessary to avoid trimming operations, because of its brittleness.

The expandable form is used for loose-fill cushioning ("peanuts") and in molded forms for close containment of fragile products.

FDA Approval

Most grades of PS comply with the requirements for food contact, provided that unacceptable materials are not introduced as coatings, adhesives, or mold-release agents.

Styrenics (Styrene-Butadiene Copolymer)

An example of styrene-butadiene copolymer (SBC), trademarked K-Resin, was created in the early 1960s and commercialized in the early 1970s by Phillips 66 Co., a division of Phillips Petroleum. A comparatively low density (1.01 g/cm^3) enables this family of reasonably tough, transparent plastics to coexist economically between the low-priced polyolefins and PS and the more expensive PCs and polyesters.

Chemistry

SBC generally does not need drying unless stored in damp conditions. Sheet resin can be mixed with GPPS and processes at only slightly higher temperatures than SBC alone.

Characteristics

These terpolymers are amorphous with low shrinkage. Easy to process alone or as a blend with other polymers, SBC can be extruded into thermoformable sheet, blown into film, or injection-and blow-molded into containers. Injection-molded containers can contain a flexible hinge similar to those made in PP. For more information on properties and costs, see Table 8.2.

Advantages and Disadvantages

SBC has high optical properties and can be blended with many other polymers including both GPPS and HIPS, styrene methyl methacrylate, PC, and PP. In most cases, the SBC is added to contribute stiffness, hardness, toughness, mechanical strength, and very high optical properties.

On the other hand, SBC has relatively high moisture and gas permeability and is attacked by many organic solvents and oils. As with many other plastics, SBC is capable of stress-cracking in the presence of fats and oils.

Applications

Packaging uses include bottles, film, and thermoformed containers such as cups and boxes for medical products, foods, and small parts. Injection- or blow-molding with highly polished, well-vented molds create parts of optimum clarity and gloss. Screw-type injection machines are preferable to provide homogeneity in the plastic melt. Blown film is useful for vegetable wraps because of its breathability and strength.

FDA Approval

SBC meets the general requirements for other styrenics used in packaging for medical products and for nonfatty foods

Urea

The thermosetting resin, urea, was developed around 1930. A hard translucent material, which takes coloring well, it is used primarily for closures and cosmetic cases. Although more expensive than some of the thermoplastics as well as the phenolics, urea's heat resistance and other fine properties make it suitable for such premium items. Beautiful colors are obtainable because urea's translucency gives a brightness and depth of color similar to opal glass.

Chemistry

The term *urea* is short for urea formaldehyde, which indicates the two main ingredients used in the manufacture of this plastic, which is a condensation reaction similar to the multistage process used to create phenolics (see page 234 in this section).

Characteristics

Compared with phenolics, urea is quite expensive. The range of colors is so much better, however, that there is little choice if appearance is critical. Being a thermoset, urea withstands high temperatures without softening, but will char at about 390 F (199 C). Under very wet conditions, it absorbs water, but this does not seem to have any serious effect.

Urea also is unaffected by organic solvents, but it is affected by alkalies and strong acids. It has good resistance to all types of oils and greases. Although urea can withstand elevated temperatures, it cannot be steam-sterilized. In addition to the shrinkage that occurs while it is in the mold, there will be shrinkage of up to 0.0095 in./in. (9.5 m/mm) in parts after molding

Advantages and Disadvantages

Urea is available in an unlimited range of colors. However, it is difficult to match pink and orchid shades, and to a lesser extent, yellow and orange, and these colors tend to fade with time especially in sunlight. Urea is a hard, brittle material, which is odorless and tasteless; it has good gloss and a pleasing translucency. It does not build up dust-attracting static electricity.

Applications

Since urea is a thermosetting resin, it can be processed only by transfer molding, injection molding, or extrusion. Cold spots in the mold will cause warpage, as will excess moisture in the material. Other defects are streaking at the weld lines; blistering due to undercure, overcure, or trapped gas; and “orange peel” surface caused by poor flow in the mold.

FDA Approval

Urea formaldehyde resins may be used in molded articles for food contact if the total extractives do not exceed 0.5 mg/in.^{2} of food-contact surface [15].

Plastic Processes

The first part of this chapter explains how the use of plastics has been greatly broadened by chemical modifications and additions to basic polymers. However, such techniques are not the only way in which plastics can be adapted to packaging needs. The machinery and production methods used to create containers from plastic polymers also have developed into sophisticated processes and are greatly responsible for plastics' leadership position in today,s packaging development.

As the number of plastics used in rigid packaging has grown, so have the varying ways in which they can be formed into packaging components.

Among the first techniques were compression molding, injection molding, and extrusion blow molding, later to be augmented with stretch and coextrusion blow molding methods.

The extrusion of plastic tubes has, to a certain extent, replaced many metal tubes; thermoforming of trays and lidding has opened up new packaging opportunities for foods and nonfoods alike; rotational molding and slush molding have created fast and low-cost methods to create larger plastic containers for semi-bulk transport. All of these modern techniques have increased the penetration of plastics into packaging and increased its utility, consumer service, and economy.

Injection Molding

The most widely used method of making plastic parts is injection molding. With this technique the plastic is melted and forced under high pressure into a heavy steel mold. After a few seconds the plastic chills and hardens, taking the shape of the mold as it sets up. The mold then opens up into two parts so that the piece can be ejected, and the mold is closed again to repeat the cycle. Molding machines are made for both thermoplastic and thermoset materials and range from 1.5 to more than 7,000 short tons (1.36 to 6,355 metric tons) in clamping force for thermoplastics and from 5 to more than 6,000 tons (4.54 to 5,447 metric tons) for thermosets. Typical small packaging products are threaded closures; dairy-product cups; small bottles, particularly for toiletries and pharmaceuticals; PET bottle preforms and base cups. Pails dominate in larger injection-molded containers.

History

The earliest machines for injection molding were straight plunger types in which a piston moved back and forth in a cylinder to force the hot plastic into the mold. An improvement in the early 1950s consisted of a two-stage plunger system. One cylinder was called the "preplasticizer," and since it did not have to inject directly into the cylinder, it could be made with a larger heat-transfer surface. The injection cylinder, on the other hand, did not have to heat the plastic, so it could be made with a larger diameter and stroke.

It was known that extrusion machines provided a more homogeneous melt, so it was logical to adapt the extrusion-screw feeding principle to injection molding. The first screw machine, introduced in 1956, was the "piggyback" type. In this machine the screw section, which angled up from the mold area, heated the plastic and forced it into a horizontal plunger located directly below. At the proper moment, the plunger moved forward to fill the mold. Today's "in-line" machines use the screw to plasticize the material and

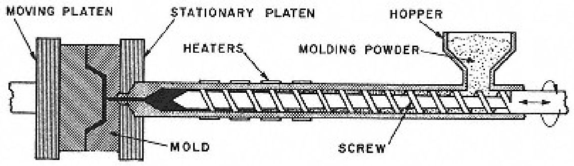

Figure 8.17.
In a reciprocating screw injection molder, the screw moves back and forth and turns, kneading pellets received from the hopper, generating heat, and melting the resin. When the mold closes, the screw stops rotating and moves forward, pushing molten resin into the mold. After the shot has been delivered, the screw resumes its rotation and moves back from the mold to repeat the process.

inject it into the mold. They do this by backing the screw away from the mold as it rotates so that molten material is pushed ahead. Then, when the mold is ready to receive the plastic, the screw moves forward like a plunger to fill the mold. These are called "reciprocating screw" machines (see Figure 8.17) and are almost the only means for handling heat-sensitive rigid PVC. The trend, today, is to more versatile machines with faster mold changeover and robotic handling of ejected parts to reduce damages.

Machine Parts

Injection-molding machines are composed of four main parts: the clamp, which holds the molds; the plastic injection unit or screw; the hydraulic or hydromechanical power system; and increasingly elaborate control systems, which automatically govern the molding functions.

The clamp must be heavy enough to hold the molds securely in-line and together, yet light enough for fast cycling action. Clamping action can be achieved by mechanical toggles, hydromechanical linkages, or full hydraulic action. Toggle and hydromechanical actions are fast, but full hydraulic systems provide greater protection for the molds. However, hydraulic systems are slower in action because of the amount of oil used to accomplish the clamping action.

Alignment of the core and cavity mold parts is critical, particularly for thin-walled parts. There are three methods of accomplishing this purpose. A "stripper-ring" method has tapers that guide the parts together. It is popular, but wears out the stripper rings in modern high-pressure systems that are used to create thin-walled containers. A "core-lock" system can be used with air or mechanical ejection machines. But a newer concept, the "floatingcore" method, now exists in which the cores and locking rings are not rigidly fastened to the core plate but can shift to better align with the cavities. It can be used with all types of ejection systems and reduces wear on the tapering aligners.

Two types of injection systems are used: reciprocating screw and two-stage injection. Large machines usually use the reciprocating screw device in which the screw moves forward to inject the molten plastic "shot," as shown in Figure 8.17. The plasticating screw must stop during this action, which somewhat slows molding speed. The two-step system, used where the speed of plasticating is important, uses a nonstop reciprocating screw that transfers the molten plastic shot to a "shooting pot," where a piston forces the material into the mold. The shot is accurately measured by the shooting pot.

In either system, the hot plastic enters the mold through a center channel called a "sprue" (see Figure 8.18). From the sprue there are "runners" to carry the molten material to each of the cavities. These runners taper in diameter and become smaller as they get closer to the cavities. Where the plastic enters a cavity, there is a restricted opening called a "gate." There are two types of runner systems: hot and cold. The hot system, generally used in packaging, maintains the runners full of hot plastic at all times. With the cold system, plastic in the runners is solidified and removed with the product. When cold-runner parts are ejected from a multi-cavity mold by "knockout

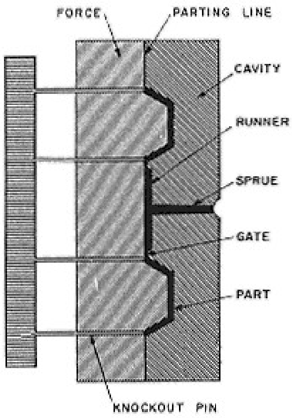

Figure 8.18.
Molten resin is forced into a closed injection mold under high pressure. After it chills and hardens, the "force" separates from the "cavity," allowing the "knockout pins" to eject the part.

pins," they are connected by a web-like plastic piece which comes out of the runners and the sprue and must be separated by breaking or cutting at the gates. This scrap material is generally reground and returned to the hopper, so that it is not wasted, but the system is slower, although less expensive than hot runners.

A good deal of the molding time is spent in cooling and solidifying the molded articles. To speed this operation, cooling channels should be located near the molding surface and coolant should be pumped at a high rate to insure maximum heat transfer.

Part Design

In planning a part to be made by injection molding, consideration should be given to a number of operating factors that have a bearing on the final appearance of the finished piece (see Figure 8.19). In addition to these suggestions, there is also the inevitable shrinkage of a plastic as it cools. The amount will depend on the type of resin used and the design of the part and usually varies from 0.1 to 4 percent. PS, for example, will shrink about 0.003 in./in. of part (30 m/cm). Shrinkage can be minimized to some extent by increasing the temperature and pressure of the plastic entering the mold, using a longer cycle, and keeping the mold cool.

Some undercuts are also inevitable and can be ejected from the mold without the necessity of expensive cam-actuated devices if the amount of deformation does not exceed about 7 percent and the approach angle is at least 30 . Undercuts up to 0.040 in. (1 mm) can be tolerated in PP, for example, if the temperature at ejection is 200 F (93 C) or higher. When designing "living hinge" sections in PP, the thickness should be between 0.010 and 0.015 in. (256 and 385 m) and should be kept as short as possible. For very large parts, hinge thickness may have to be slightly heavier.

Special types of gates speed or retard plastic flow, depending on the configuration of the part. Where plastic flow distances are great, multiple gates hasten flow. For ejecting parts from the mold, knockout pins are the easiest and simplest devices to use. But if these might cause distortion, it is better to use a blade knockout or a stripper plate, which may completely encircle the part and, thus, distribute the force all around the edge. Vacuum or poppet valves sometimes are used on deep-cored parts or air ejection may be used to aid removal. Highly polished and chrome-plated molds will produce parts with a high gloss, but may cause problems in ejecting because of the difficulty in breaking the vacuum. Vapor honing or sand blasting will provide a slight surface roughness to offset this problem. Molds that are used with PVC have to be plated with chromium, nickel, or, in some cases, gold in order to resist the corrosive action of the acid degradation products of PVC.

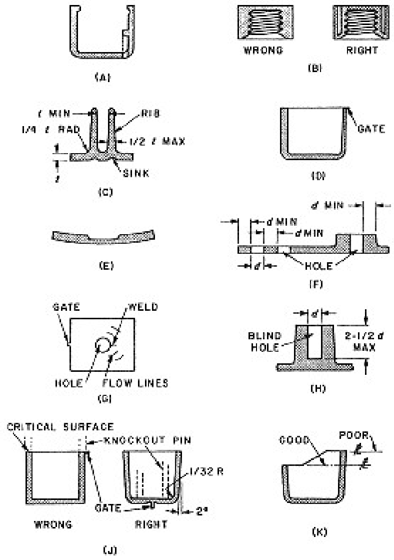

Figure 8.19.
Successful injection molding depends on careful part design: (A) Undercuts should be avoided as much as possible so the mold won't have to release the part from the core. To avoid this, let the cavity project up through the part to form the underside of the undercut, as shown in the lower right. (B) Uniform thickness should be provided by coring out heavy sections. This will reduce cost and prevent unsightly sink marks. (C) Ribs should be less than half the thickness of the adjoining wall so shrinkage will not cause a sink mark on the opposite side. For the same reason, ribs should not be closer than the wall thickness (t) apart. Avoid sharp inside corners; a radius of at least one-fourth the thickness of the wall is preferred. (D) The gate should be at the thinnest part of the piece to minimize the flow resistance. The plastic entering the mold should impinge upon some part of the mold, to avoid laminations in the finished piece. (E) Changes in thickness will cause warpage because of differences in shrinkage from one section to another. (F) Holes should not be closer together or closer to an edge than the diameter of the hole. The wall of a boss should not be less than the diameter of the hole. (G) Holes should not be directly opposite a gate, where they may cause flow lines and a weak weld. (H) Unsupported core pins longer than 2.5 times the diameter may bend from injection pressure. (J) Sharp corners should be avoided. Draft of at least 2 is preferred for easy part removal. The gate should be recessed, if possible, to avoid a degating operation. Knockout pins that may mark a critical surface should be relocated. (K) The parting line of the mold should be kept flat whenever possible to minimize problems fitting mold parts together.

Mold-Making and Costs

Molds usually consist of two main parts: the female cavity, which forms the outside of the piece, and the male portion, which shapes the interior (see Figure 8.18). There may be only one cavity in which case the mold makes one piece at a time, or there may be as many as 16, 24, or more cavities, depending on the size of the molded article, the output required, and the size of the molding machine (see Figure 8.20). The greater the number of cavities, the higher the cost of the mold, but the lower the cost of the pieces being produced. Molds also can be configured to hold separate inserts, such as bolt screw fittings, which are then molded into the part in specialized molding machines.

Various techniques are used in making molds. The simplest is direct machining of a solid block of metal, usually done today on numerically or computer-controlled machines. Where a number of shallow cavities are needed, it also is possible to use a "hob," a replica of the part in hardened steel that is forced into the die block under tremendous pressure. It takes as much as an hour for the hob to sink into the die in this way, but every cavity made with the same hob will be precisely the same. Electrical discharge ma-

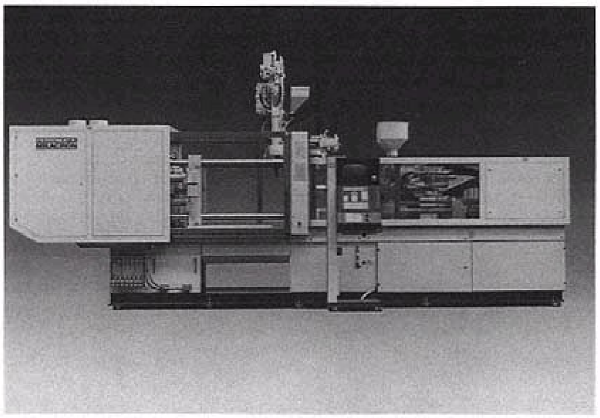

Figure 8.20.
Hydraulic injection molding machine with two injection units can produce 12 two-color 28-mm closures per 5.5-sec. cycle. (Source: Cincinnati Milacron Marketing Co., Batavia, Ohio, used with permission.)

chining (EDM) is used for at least a part of the work in most mold shops. It is useful in matching the mating faces of the mold, to reduce flash, especially with a complicated parting line. By bringing the faces together in the EDM machine, a perfect fit can be produced. This system also is used for roughing out the cavities, and fairly good accuracy is obtained with very little finishing and polishing required.

Molds must be vented to allow air to escape. These vents consist of grooves about 0.5 in. (1.3 cm) wide and 0.0015 in. (0.04 cm) deep at the parting line. They also can be put in by grinding flats on the knockout pins or by grooving the inserts in the mold. Molds are usually made of tool steel, but sometimes experimental molds are made of beryllium-copper. These are cheaper to make, easier to alter or repair with a heliarc welding unit, and conduct heat more rapidly for faster cycling. Being softer than steel, beryllium-copper requires a heavier section around the side walls for support against the molding pressure. It also is used as inserts in steel molds to speed heat transfer, since it is about ten times more conductive than steel. Because this material does not hold up well under abrasive conditions, it cannot be used for compression molds.

Cost of injection-molded pieces can be approximated by weighing a model, or by calculating the weight from dimensioned drawings and applying the current price per pound of the resin. To this is added a factor for machine time, usually equal to the material cost—or more, if it is a small or intricate piece. Amortization of the molds also should be included, figured over a 2- or 3-year period. If the mold cost is not known, add about one-fourth of the material cost for a rough figure, and add a like amount for packing and shipping. As an example: an injection-molded dairy-style PP cup that weighs 0.75 oz (21.3 g) requires about 2 cents worth of material. Adding another 2 cents for machine time, 0.5 cents for mold amortization, and 0.5 cents for packing and shipping brings the total part cost to about 5 cents.

Mold Specification

An important factor in the design of injection-molded plastic packaging components is the specification of the tooling. Although this frequently is left for others to decide, the packaging engineer should give some thought to the various aspects of mold making while the package is still under development. If the expected quantity of finished packages is large, the cost of the molds and other manufacturing equipment is insignificant and the very best molds will be cheapest in the long run.

On the other hand, for short runs, mold cost can add considerably to the final cost of the parts, and it would be well to weigh the merits of alternative toolings. For example, some parts lend themselves to injection molding or thermoforming, and the choice may be strictly one of economics. Tooling costs for thermoforming are a great deal less than those for injection molding, but the piece cost for thermoforming might be greater in the end because of scrap loss and the higher cost of extruded sheet.

Then, there is the question of who does the molding. Thermoforming usually can be accomplished with some ease in-house on relatively inexpensive equipment. However, more complex injection molding is usually done outside. In the latter case, it is well to choose a supplier as early as possible and to work closely with him in the development of the final design. An agreement should also be worked out with the supplier in the beginning as to secrecy and patent assignment, ownership of tooling, cost of development, and similar details. It is much easier to get such matters settled at the beginning than to try to reach an agreement after considerable time and money have been spent. Following are some of the points that should be settled with the supplier at the outset:

(1) Sample tools: estimated cost, ownership, removal surcharge (usually 30 percent), estimated life, payment terms

(2) Sample parts: estimated cost, approvals in writing, delivery dates

(3) Patent assignment: assignment costs and legal fees, infringement protection, secrecy agreements

(4) Production molds: number of cavities, back-up molds, estimated cost, payment terms, ownership, removal surcharge, estimated life, maintenance and repairs, cancellation terms, adaptability to other (competitor's) molding machines, exclusive use, liability and casualty insurance, tooling and part prints, replacement costs

(5) Quality control: tolerance levels for warpage, limit samples and colors, part sorting costs, QA test methods, gauge costs, time limit for claims, contingent losses (assembly costs)

(6) Packing and shipping: overruns, underruns, and methods

Compression Molding

In 1907 Dr. Leo Hendrik Baekeland mixed phenol-formaldehyde resin with wood flour and put it into a mold, which was used for making rubber parts. With heat and pressure he was able to produce the first organic plastic pieces. The same basic method still is used today to mold thermoset plastics, which once polymerized and molded, cannot be remelted.

Compression molding in packaging, once used mainly to produce threaded thermoset closures, has largely been replaced by injection molding. Ovenable containers have caused some resurgence, initially for airline dinnerware and more recently in glass-filled thermoset polyester trays for frozen foods designed to go directly to microwave or convection ovens and then to the table.

Compression molding is simple and low in tooling costs. Molds are made from aluminum, plastic, or steel. The process also is slow. Typical times for heating and polymerization in the mold are from 0.5 to 1 min or more, depending upon size. However, there is also little or no material waste, secondary finishing operations, or mold wear. The parts, naturally, have good heat resistance, are dimensionally stable, and exhibit little or no shrinkage.

In compression molding the molds are heated to about 300 F (149 C) and granular material is put into the mold with a slight excess. The excess squeezes out as the two parts of the mold come together and must be trimmed off in a subsequent operation (see Figure 8.21). Pressures of about 2,000 psi (13.8 MPa) are applied, and the material is allowed to cure. It is then ejected from the mold and the flash is removed by tumbling in a revolving barrel machine made for this purpose.

Molded phenolic parts undergo some shrinkage and will continue to shrink for several hours after removal from the mold. Actually, the shrinkage even continues in a very slight amount for some months afterward, but this long-term shrinkage is significant only for very closely fitting parts. Where this must be controlled, it is possible to "post-bake" the pieces and virtually stop all further dimensional changes. Eight hours at 350 F (176.7 C) will provide a shrinkage of about 0.005 in./in. (5 m/mm) in a typical phenolic item.

The thermoset materials usually used in compression molding are phenol and formaldehyde or urea and formaldehyde, which polymerize permanently with heat. Continued heating at a slightly higher temperature then causes the material to "set up." Usually fillers are mixed with the resin to improve processing qualities and toughness and reduce cost. The fillers can be wood flour, asbestos, graphite, chopped canvas, mica, sisal, paper, synthetic

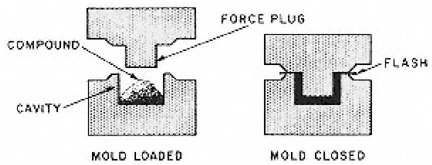

Figure 8.21.
In compression molding, a slight excess of powdered resin is put into a heated mold. When the mold closes under high pressure, the excess squeezes out as flash and must be removed. The plastic cures in a minute or so from the heat of the mold, the mold opens, and the part is ejected.

fibers, glass, or similar materials. Thermoset closures are more expensive than metal closures, but their appearance is often viewed as better suited to pharmaceutical and cosmetic packaging (see Chapter 13, Closures and Seals for more information).

Rotational Molding

For small quantities of large items where the cost of molds is an important factor, or in development of a new container where changes must be made quickly and inexpensively, rotational molding may increasingly be the method of choice.

This technique, also called rotomolding or rotational casting, produces seamless, hollow parts of uniform thickness and without the internal stresses that can be created during conventional molding or thermoforming. In packaging, rotational molding is generally used for large containers such as drums, carboys, and plastic pallets. The minimum wall thickness that can be produced is about 0.030 in. (0.8 mm). The molds are less expensive than injection molds, but a little higher in cost than those for thermoforming. Material costs are higher for the powder or liquid mixtures used in this process than for the beads used for injection molding, and the production rate is low per mold. However, almost any hollow object of any shape can be formed. Double-wall parts, intricate details, undercuts, and inserts are all feasible. As a result, it is one of the fastest growing plastic processes today, expanding at an annual rate of 25 to 30 percent.

Vinyl plastisols were the first materials used in this process, followed by urethanes. Now, PEs are generally the plastic of choice, although such other thermoplastics as PET, PP, PVC, PC, and nylon are used as well.

In the process, a weighed amount of finely powdered plastic is put into the mold by hand. The mold is mounted on a spindle which carries it into an oven. While it is in the oven, the mold is heated to about 500°F (260°C) by hot air while spindles rotate the mold in two axes so that the inside surface becomes uniformly coated by the plastic as it melts (see Figure 8.22).

The mold is mounted as close to the axes of rotation as possible, so that the centrifugal forces will not cause too much variation in wall thickness. Rate of rotation is about 12 rpm around the major axis and about 3 rpm around the minor axis. Higher speeds sometimes are used to force the plastic into very narrow recesses in the mold. It may take as long as 10 min to heat the plastic enough to coat the inside of the mold uniformly. The spindle then carries the mold into the cooling chamber. Here the mold is sprayed with cold water to solidify the resin. Cold air also is used for this purpose, either with or without the water spray.

The molds are vented to the atmosphere so that excess pressure does not

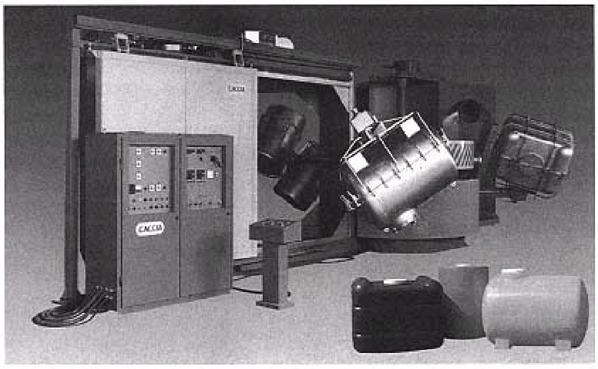

Figure 8.22.
In a rotational molding process reminiscent of the way hollow chocolate bunnies are made, powdered resin is put into a cold mold. As it rotates in two directions, heat is applied to melt the resin and uniformly coat the inside surface, forming the part.
(Source: Caccia Engineering S.p.A., Samarate, Italy, used with permission.)

build up during the molding cycle, although a small amount of pressure is sometimes desirable to keep the plastic in contact with the mold surface. No draft or taper is usually necessary in the design of the parts. Flat panels tend to shrink away from the mold as they cool and should be avoided. This shrinkage occurs especially if the mold is cooled too rapidly, with consequent warpage and brittleness.

Machines range from a simple pot with a single-axis of rotation, which make mostly open-ended containers of a liquid/powder mixture in a process also called slush molding or casting, to a multi-mold carousel for smaller items and shuttle machines for bigger parts. Some machines, as shown in Figure 8.22, are self-contained and have a circulating system that brings heating and cooling oil to the jacketed mold, so that no oven is required. The molds are generally made of steel, although aluminum or electroformed copper-nickel is sometimes used for small sizes.

Recent developments include the use of pre-colored plastics that can be bonded in different layers to recycled plastics and foams and the injection of foams between solid walls for stiffness and strength in large parts. Molded-in decoration, akin to in-mold labeling (see Chapter 12, Labeling and Decorating), can produce permanent designs, which resist scuffing and wearing.

Blow Molding

The history of blow molding dates to before World War I, when baby rattles, dolls, and ping-pong balls were made of celluloid by this process. In fact, if we go back further, we find the ancient Egyptians blow molding articles of tree sap that hardened and eventually became amber.

For practical purposes, however, the industry got its start when Ferngren and Kopitke combined a plastic-extrusion process with blow molding and sold their idea to the Hartford Empire Company in 1937. The Plax Corporation was set up under James Bailey to develop the process. During World War II, LDPE was introduced and proved to be compatible with this technique. Other companies soon followed, designing their own machines and molding "squeeze" bottles. But their machines were kept secret, and it was not until 1958 that such machines became commercially available. One of the earliest retail packages to use the new squeeze-bottle principle was Stopette deodorant. Introduced around 1947, it was an instant success.

In 1957 the Ziegler low-pressure process for making HDPE caught the attention of bottle manufacturers, and by 1959 five companies were making detergent bottles of this material. Today there are more than 350 manufacturers making nearly 9 billion blown plastic containers every year.

Approximately 6.4 billion lb of plastics went into blow-molded containers in 1995, an amount that is growing annually. HDPE accounts for 55 percent and PET for 38 percent with the remaining 7 percent split among PP, PVC, LDPE, LLDPE, and PS in that order (see Table 8.4). Containers made from these materials vary widely in cost (see Table 8.5), but each material is used where its specific properties give it an advantage (see Table 8.2).

The most widely used material for bottles is HDPE, which costs a little more or less than LDPE, depending on availability and market variations,

TABLE 8.4. Plastics Used in Blow-Molded, Thermoformed, and Rotomolded Containers in 1995 (million lb).

Plastic	Blow-Molded	Thermoformed	Rotomolded
HDPE	3,488	680	-
LLDPE	18	42	348
LDPE	68	-	106
PET	2,420	154	-
PP	183	218	-
PS	10	322	-
PVC	173	859	-
TOTAL	6,360	2,275	454

TABLE 8.5. Bottle Cost Versus Resin Type ($/1000).

Bottle Size, oz	LDPE	HDPE	PVC	PET	Glass
2	-	180	390	260	590
4	-	230	430	310	-
6	-	290	-	-	-
8	630	320	600	570	590
12	690	400	-	-	-
16	790	420	830	690	630
32	-	770	960	-	1,000

but is stiffer and has a lower permeation rate to moisture. Because of its stiffness, it can be made into bottles with thinner walls, and therefore the final cost is less (see Table 8.5). LDPE is used where greater clarity and a soft squeeze-bottle texture is desired.

PET is the fastest growing bottle plastic particularly in the field of soft drinks and bottled water and especially for larger sizes above 1.5 L (44.4 oz). It was necessary to develop a special stretch-blow technique to produce the required rigidity and impact strength in PET. With this process, the parison is extruded or injection-molded in the usual way and then cooled to the stretching temperature, which is somewhere between the glass-transition temperature (145 F, 62.8 C) and the melt-transition temperature (425 F, 218.3 C). A core rod stretches the parison longitudinally, and air pressure stretches it laterally to fill the mold. Depending on bottle size and market variations, PET may be more or less expensive than glass, but the factors of safety and reduced shipping and handling weight give it a definite advantage in larger sizes. Other products being sold in PET bottles include cooking oils, mouthwash, and salad dressings.

The next most important material for blow molding is PP, which has a strong resistance to stress cracking and is, therefore, used for aggressive liquid products that destroy HDPE containers. About two-thirds of the poundage is used for consumer product packaging. Of this, about half goes to pharmaceutical products, where injection blow molding of small PP containers is a volume business. High melt strength enables PP to be used in larger containers, too, up to several gallons in size. Random and impact copolymers are generally the materials of choice for blow molding PP, since they boost its impact strength at low temperatures. An improved method of blow molding PP, the Orbet process developed by Phillips Petroleum Co., biaxially orients the plastic as it is blown to provide exceptional clarity, greatly improved tensile and impact strength, and better barrier properties than unoriented PP. Clarifying additives also are helping expand PP's market share.

Despite the cries of environmentalists, PVC has held on to third place in bottle plastics. It has good impact strength, is relatively inexpensive, and can be perfectly clear and colorless. In comparison with HDPE, PVC has only about one-fifteenth the oxygen transmission rate. This permits PVC to be used for hair-waving formulas and shampoo products, which are vulnerable to oxidation.

PVC is compatible with oils and most of the organic solvents. Oil resistance is high, which makes this material a good choice for household cleaners containing pine oil. Even cigarette lighter fluids are compatible with PVC. It's not as good as PE for retaining aqueous formulas, however, and water loss can range from 2 to 20 percent per year. Also, because it has a highly glossy surface, scratches stand out more than in some other bottle plastics.

Early on, PVC was difficult to handle in molding machines, too, because of its tendency to degrade when heated. For this reason, extreme cleanliness must be observed, and equipment must be designed with no pockets or crevices where the plastic can hang up. Between the critical degradation temperature of 460 F (238 C) and the operating temperature of 400 F (204 C) there is little margin for fluctuations. It is recommended that bottles be vibration and drop tested after standing at least 24 hours filled with actual product (see Chapter 18, Preshipment Testing). Also, because of an increasing brittleness at low temperatures, it is suggested that drop tests be made at a temperature of 0 F (-17.8 C) as well as at ambient temperatures. The rate of shrinkage on cooling is very low, but PVC has a lot of elastic memory and will snap back if it is not thoroughly cooled before it is taken out of the mold.

Other materials are less important commercially, but may have special applications. PC, for example, has amazing strength, excellent clarity, and good resistance to oils. It is stain-resistant, has no odor or taste, and can be steam-sterilized. Some grades are approved by FDA for food products. Its biggest drawback is high cost, but if the bottles can be returnable or the application is one where super-strength is super-critical, it can become a material of choice.

Temperature must be controlled very carefully, as the viscosity changes rapidly with small changes up or down. PC bottles are damaged by alkaline washing solutions, and special cleaning materials are necessary. Handles or finger-grip ears cannot be molded at this time.

Another plastic used in small quantities for bottles is PS. Crystal clear and rigid, it has a brilliance equal to glass. It is very brittle, but investigations of metallocene technology have shown promise of creating a much tougher material. PS parisons can be injection molded and formed into bottles by air pressure in a scrapless operation. The material has a fair barrier to moisture and gases, but is dissolved by the esters and ketones in essential oils. Careful shipping and storage tests are strongly recommended before using this material in bottles.

Extrusion Blow Molding

Of the three methods for blow-molding containers, the most widely used technique is called "extrusion blow molding." It consists of extruding a hollow tube called a "parison" in a downward direction. When it reaches the desired length, two open halves of a mold that surround it are closed, pinching the bottom of the tube closed, but leaving an open top port for admission of a blow tube for the injection of air (see Figure 8.23).

In this process molds can be stationary to receive an intermittently extruded parison, and the entire blowing action takes place in a single station. A continuously extruded parison also can be formed where the mold is raised to capture the parison, then lowered for blow molding. Continuously extruded parisons also can be captured by side-mounted molds, which shuttle in and out to capture a parison, blow, and discharge it without stopping, a faster operation that is particularly appropriate for PVC, which must be closely controlled in melt temperature to avoid degradation and browning of the plastic (see Figure 8.24).

For the ultimate in output from continuously extruded parisons, there is the wheel machine on which are mounted many molds that continuously rotate past an overhead extruder and blow and discharge containers as the wheel rotates. Since this system requires many molds and lengthy changeovers, it is practical only for long runs of single container sizes, but

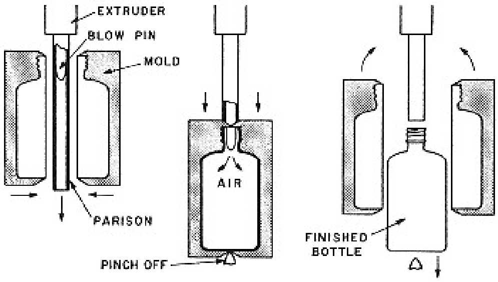

Figure 8.23.
In one form of blow molding, molds move up and down, closing around the parison as it is extruded, moving down as air is blown in to expand the warm, soft resin against the mold, releasing the finished part, and moving up to meet the parison again.

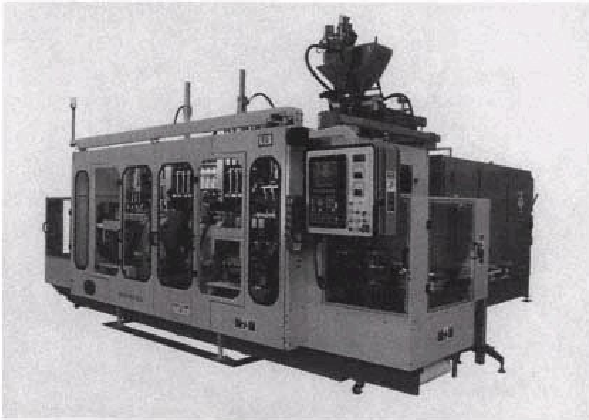

Figure 8.24.
A shuttle blow molder offers higher output potential because it captures continuously extruded parisons, blows, and discharges containers without stopping.
(Source: Bekum America Corp., Williamston, Michigan, used with permission.)

has an output capability for the biggest plastic-bottle applications. In this machine, individual bottles usually are separated from the continuous parison after cooling and opening of the molds.

The two types of extrusion used in injection molding also are used in all forms of blow molding. The reciprocating screw and dual screws are preeminent for small containers and parts (see Figure 8.25). They are fitted with a secondary accumulator and ram for intermittent parison extrusion. An accumulator-head extruder with a plunger feed is used for larger containers up to and including plastic drums.

All extruder heads can be fitted for parison programming. In an ordinary head tool, the position of the central mandrel within the extruder die is fixed to deliver a parison with a uniform wall structure. In a programmed head, the mandrel can be adjusted to vary the wall thickness of the parison at various positions over its length (see Figure 8.26). This places more or less plastic where it is needed in the final container: more plastic in the finish for strength, more where the plastic has to stretch farther to fill the mold, less where thin and small sections do not require as much material. In the actual molding operation, the warm, soft plastic stretches out under air pressure and takes the shape of the mold (see Figure 8.23).

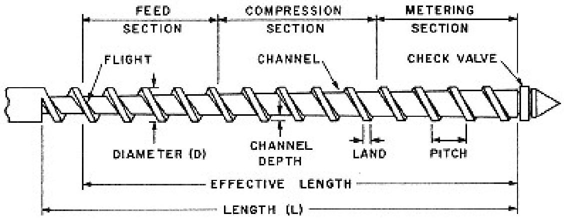

Figure 8.25.
Extruders in both injection and blow molders use a turning screw in an ever shallower channel to generate heat, melt resin pellets, and perform mixing chores.

In the extrusion-blow-molding process a small tail remains attached to the bottom that must be removed. In the past, extrusion-blow-molded bottle finishes had to be reamed to the proper tolerance, which caused problems when chips fell into the containers. Today, most blow-molding machines automatically perform the trimming operation at the molding station and the neck finish is trued up by a cooperative effort of the blow pin and mold neck ring while the bottle is still in the mold. Handleware and wide-mouthed containers, however, still are finished in a down-line trim press.

Extrusion blow molding is preeminent in the creation of small to large containers (even up to sizable tanks), odd shapes of all kinds and dimensions, offset necks, and handled ware. Molds are relatively inexpensive and often made of aluminum for both short or long runs.

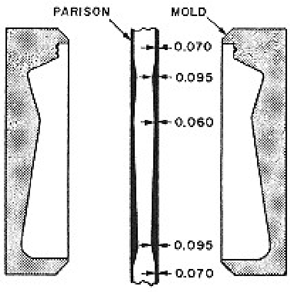

Figure 8.26.
A programmed parison tailors wall thickness to suit the geometry of the container, adding strength where needed and minimizing thin corners.

Injection Blow Molding

Another molding method is a two- or three-stage operation in which the parison is injection-molded instead of extruded and transferred on a core rod to the blow-molding station. This early two-stage system had the disadvantage of leaving the two stations idle during part removal. But in 1961, Gussoni of Italy added a third part removal station to speed the process, a technique universally used today. In fact, sometimes additional stations are added for bottle conditioning, inspection, and/or decoration. Also recently developed is bottle formation without flash, creating much neater bottles for toiletry and cosmetic use.

A related process called "displacement blow molding" involves placement of a measured amount of melted plastic into a preforming container and then inserting a core rod, which displaces the resin into the neck-finish forming area for blow molding. The process is used for creation of very precise and small bottles. In fact, the injection molding of packaging in general is targeted to such markets as pharmaceuticals which require bottles of high quality and precise dimensions.

The injection process permits great molding accuracy and weight control, particularly in the neck finish, which can be held to tolerances as low as ±0.004 in. (102.6 m). This is important when plugs or other fitments are to be applied and for special designs, such as finishes for child-resistant and tamper-evident closures. The bottles can now be made flash-free and require no post-finishing. However, mold costs are higher with this process. Injection blow molding usually is limited to uniform shapes and to bottles 8 oz (236.6 ml) or smaller, although bottles as large as 16 oz (473 ml) have been made in recent years. Any resin that can be blow molded can be handled in this process.

Stretch Blow Molding

A third molding method can be used with plastics capable of linear orientation such as PET, PVC, PP, and amorphous nylon. The largest application is for beverage bottles. In stretch-blow, a preformed parison is conditioned to just above the glass-transition temperature to prevent crystallization and is stretched, oriented, and blown in either a one- or two-step process.

In the two-step sequence, "preforms" are usually made separately—even in another plant—and then brought to a reheat-blow machine. In the one-step system, every stage is performed on a single in-line machine. The parison-forming and blow-molding operations are similar to those of extrusion blow molding. Advantages of stretch-blown bottles are greatly increased transparency, surface gloss, impact strength, and stiffness. This also enables very thin-walled structures for lower container costs.

A special usage of blow molding is in aseptic packaging, which is best performed by blowing, filling, and closing the containers in a single operation. The entire molding sequence is enclosed in a sterilized cabinet, and presterilized liquid product is filled into the container, sometimes while it is still in the mold. Closure is by means of a heated die, either a part of the mold or a separate fixture, which forms an attached, twist-off cap. A second type of aseptic operation forms a bottle in the conventional manner under sterile conditions and, after filling with sterile product, applies presterilized closures while still in the sterile environment. Construction of such machines is rigorous, both in the use of stainless steel and in structural design that assures initial sterility as well as a comprehensive system of clean-in-place liquid and/or vapor media that continue to maintain sterility throughout operation.

Mold Design

The two most important factors to be considered in making a mold for blow molding are heat-transfer properties and resistance to wear. Aluminum, steel, and beryllium copper are the metals of choice, depending upon the type of blow molding and the nature of the plastics being molded. For example, aluminum—usually sandblasted with grit to avoid the entrapment of air—frequently is used for polyolefins.

Hard, corrosion-resistant beryllium copper offers high heat transfer and great resistance to wear. It often is used for PVC and in molds containing fine detail. Molds are polished for PVC and chromium coated for more finely finished surfaces. However, it should be noted that beryllium copper costs more than aluminum, is heavier, and takes more time to machine.

Parison cavities for injection blow molding are made from hardened tool steel, as are the cavities for stiffer plastics and neck rings and core rods for all plastics and processes.

The neck and base portions of a mold generally are made as separate pieces so that they can be machined and finished more easily and to allow flexibility in the interchange of finishes. The two halves of the mold must line up perfectly, as any misalignment will result in thinning along the parting line. Clamping pressures are relatively light, in comparison with injection or compression molds, since they need only to resist pressures of around 5 psi (0.035 MPa) in the cavities.

Proper cooling of the mold is necessary to get the shortest possible cycle time and a uniform surface appearance. Water channels in each mold half can be drilled out, or in a cast mold can be cored. Water-cooling lines are located perpendicular to the mold axis and as close together as possible since as much as 80 percent of molding time is taken up with cooling, and any improvement can result in a marked increase in output.

While molded parts usually are cooled externally by the mold, internal measures have been developed as well to reduce the expensive cooling time and overcome the poor thermal conductivity of most plastics. Liquid nitrogen or carbon dioxide as the blowing agent instead of air is one approach. Very-cold air containing water vapor is another. Production rates, it is reported, can be improved as much as 50 percent.

Container Design

One characteristic that a designer must keep constantly in mind is shrinkage. Since the plastic is being stretched in a semi-molten state, stresses are built into the resultant container. In common parlance, that means that "plastic memory" makes it want to return to the shape of the original parison. Most of the shrinkage takes place as the container cools after molding. For example, PE shrinks about 3 percent. Days later, though, a small amount of deformation will still be taking place. This is not likely to be a problem, however, unless there are close-fitting parts, which must move freely.

The easiest shape to blow is a cylinder. This yields a uniform wall thickness and, consequently, a very economical container. However, if the product is apt to cause "bottle collapse," the round shape will show this up very quickly. Detergents, which absorb oxygen from the headspace, can exhibit this phenomenon. It starts to occur in 3 or 4 days and becomes severe usually within 2 weeks, developing a vacuum in the container equivalent to about 5 in. (12.7 cm) of mercury. For this type of product, then, it becomes necessary to use an oval bottle with flat panels to conceal the distortion.

Ovals are the next best shape to mold; rectangular or odd shapes, the least desirable. With the latter, the added stretch makes the parison thin and creates a difficulty in filling out the mold. Sometimes, then, the wall is too thin at the farthest container surface. There is also a certain amount of "drawdown," or stretching of the parison by its own weight that causes the top portion to be thinner than the bottom. It is possible to at least partly compensate for this condition with programmed parisons (see Figure 8.26).

Production-line stability of bottle handling also can be a problem because of the light weight of plastic containers—particularly those molded of PET—unless a broad base is an element of the container design. Even with a stable base, some high-speed lines require such mechanical assists as vacuum-, side-, or top-belt conveyors, flighted screw feeds, or molded or machined pucks to keep containers upright and in place.

Cylindrical and rectangular shapes are the easiest to handle on conveyors. Containers with oval, triangular, and diamond-shaped cross sections tend to jam between guide rails. Rectangular shapes should have rounded corners so that they do not catch on the edges of rails and star wheels, and also to allow mechanical positioning fingers to enter between them. Tapered containers are less controllable than straight-sided.

The base of a plastic container should be indented or, to borrow a term from the glass industry, it should have a “push-up,” so that any ovality in the container bottom from the molding operation does not cause container instability. However, the peripheral bead should be at least 0.25 in. (6.4 mm) wide to avoid catching in conveyor or dead-plate gaps. This indented area is also the location of molder or manufacturer marks and sometimes the number of the specific mold that made the container. This enables one to identify the source of a container and often the specific cause of a problem in a single container.

Flat areas in the side walls near the bottom and top of a container provide control points for secure handling and transfer in star wheels or pocketed turrets. If it is necessary to transfer from one turret to another, two flats close to each other are useful.

The size of the finish and the neck opening should be as large as possible for maximum filling efficiency and to avoid turbulent air removal that can spill product. Application of screw caps and warehouse stacking in shippers strain the shoulder sections of containers. A conical shape imparts the greatest strength under such conditions. Flat horizontal shoulders are the worst and can lead to collapse of the bottle at the finish due to the great forces generated by warehouse stacking of tiered pallet loads. A gripping surface near the shoulder for the capping machine will resist torquing forces better than one near the bottom. Screw threads of the buttress type are best with plastics since they are less likely to jump threads or to creep when torqued down than the threads used on glass containers.

The examples in Table 8.6 and Figure 8.27 show maximum and minimum outside (T) and inside (E) thread dimensions and are an average of measurements taken across the major and minor axes of the bottle finish. H is the height of the bottle finish from the top of the finish down to a point opposite the bottom of the bottle bead or shoulder start of the bottle shoulder. A generous straight section before the start of a thread, known as the S (for start) dimension, helps avoid cocked caps. It is measured between the top of the bottle finish and the start of the thread. I is the inside diameter of the bottle neck, which varies with the size of the bottle as shown in the listing of bottle sizes (in mm) for series 400, 410 and 415 bottles.

Threaded finishes should have double- or triple-lead threads, if possible, and the number of turns for sealing should be kept to a minimum. If the thread is depressed slightly at the parting line, it will keep any flash from interfering with the fit of the closure. Plugs and fitments should be well tapered for easy assembly, but should not taper all the way up; if they do, they may loosen with vibration. A slight undercut will help keep them in place.

TABLE 8.6. Standard Dimensions for Selected Plastic Bottle Finishes.

			T		E		H		I
Type	Series	Size mm	max.	min.	max.	min.	max.	min.	min.
Shallow, CT	400	18	.704	.688	.620	.604	.386	.356	.325
		20	.783	.767	.699	.683	.386	.356	.404
		22	.862	.846	.778	.762	.356	.980	.483
		24	.940	.924	.856	.840	.415	.385	.516
		28	1.088	1.068	.994	.974	.415	.385	.614
		30	1.127	1.107	1.033	1.013	.418	.388	.653
		33	1.265	1.241	1.171	1.147	.418	.388	.791
		38	1.476	1.452	1.382	1.358	.418	.388	.987
		40	1.580	1.550	1.486	1.456	.418	.388	1.091
		43	1.654	1.624	1.560	1.530	.418	.388	1.165
		45	1.740	1.710	1.646	1.616	.418	.388	1.251
		48	1.870	1.840	1.776	1.746	.418	.388	1.381
		51	1.968	1.933	1.874	1.839	.423	.393	1.479
		53	2.067	2.032	1.973	1.938	.423	.393	1.578
		58	2.224	2.189	2.130	2.095	.423	.393	1.735
		60	2.342	2.307	2.248	2.213	.423	.393	1.853
		63	2.461	2.426	2.367	2.332	.423	.393	1.972
		66	2.579	2.544	2.485	2.450	.423	.393	2.090

Table 8.6 (continued).

Type	Series	Size mm	T max.	T min.	E max.	E min.	H max.	H min.	I min.
		70	2.736	2.701	2.642	2.607	.423	.393	2.247
		75	2.913	2.878	2.819	2.784	.423	.393	2.424
		77	3.035	3.000	2.941	2.906	.502	.472	2.546
		83	3.268	3.233	3.148	3.113	.502	.472	2.753
		89	3.511	3.476	3.391	3.356	.550	.520	2.918
		100	3.937	3.902	3.817	3.782	.612	.582	3.344
		110	4.331	4.296	4.211	4.176	.612	.582	3.737
		120	4.724	4.689	4.604	4.569	.700	.670	4.131
Medium, CT	410	18	.704	.688	.620	.604	.538	.508	.325
		20	.783	.767	.699	.683	.569	.539	.404
		22	.862	.846	.778	.762	.600	.570	.483
		24	.940	.924	.856	.840	.661	.631	.516
		28	1.088	1.068	.994	.974	.723	.693	.614
Tall, CT	415	13	.514	.502	.454	.442	.467	.437	.218
		15	.581	.569	.521	.509	.572	.542	.258
		18	.704	.688	.020	.604	.632	.602	.325
		20	.783	.767	.699	.683	.757	.727	.404
		22	.862	.846	.778	.762	.852	.822	.483
		24	.940	.924	.856	.840	.972	.942	.516
		28	1.088	1.068	.994	.974	1.097	1.067	.614
		33	1.265	1.241	1.171	1.147	1.289	1.259	.791

SPI's Plastic Bottle Institute has developed dimensional standards for most popular plastic bottle finishes in a series of nine documents.

Source: The Plastic Bottle Institute, Washington, D.C.

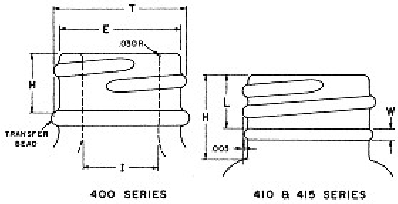

Figure 8.27.
Two common finishes show neck dimensions.

Thermoforming

The various types of thermoformed packages include skin packaging, blister packaging, and formed primary containers and closures. Their common characteristic is that they start with flat sheet or film. This material is heated until it is soft and pliable and then shaped by vacuum, pressure, and dies—or any combination of these. Much thinner walls can be made by this process than by any other method of fabrication. The cost of the material is therefore lower, but this is offset to some degree by high scrap losses. Molds for thermoforming are much less expensive than for other plastic processes, ranging from $1,000 to $2,000 for the simplest. Tooling-up time is a matter of weeks compared to the months that are necessary for blow molding or injection molding.

The process of heating and forming sheet plastics originated in 1936, when the use of shrinkable film on meats was introduced in France. During World War II, this method was used for making contour maps out of printed plastic sheet. It was not until the early 1960s, though, that it came into general use in packaging when containers and lids for dairy products were first introduced. Later, PS foam sheet was formed into trays and cartons for eggs, meats, and produce. Today, these and many more applications consume more than 2 billion lb of sheet.

For thermoforming it is possible to use any sheet thermoplastic material. In practice, however, certain materials have been found to satisfy the requirements of packaging better than others because of transparency, odor, processing characteristics, or costs (see Table 8.2). The most widely used ones in order of volume are PVC, HDPE, PS, PP, PET, and LLDPE.

At the top of the list is semirigid PVC. It's widely used in food packaging for its transparency and moisture barrier, which can be enhanced with a PE layer or more stringent barrier material to reduce oxygen permeation. This material forms a stiff and protective cup or tray as does HDPE, second in usage for both food and nonfood applications because of its inert nature and lack of odor. PP is also in the running and preferred with some foods. It is very machinable and capable of deep draws. PET, which withstands temperature better than the polyolefins, has dominated dual-ovenable food packaging comprising heat-and-eat frozens that can thawed and cooked in either microwave or conventional ovens. Blisters intended for solid articles are the province of HIPS, which affords a sparkling clear view of the product and is machinable, reasonably strong, and economic. Other materials like acrylonitrile-butadiene-styrene (ABS) and PC are used for specialty applications where strength is more important than cost.

Thermoforming Processes

The basic technique in thermoforming is to suspend a sheet of plastic in a frame that grips it all around the edges. The sheet is heated until it softens and is then sucked down over a mold by vacuum. When it is cool, it is stripped from the mold and trimmed. Such simple machines as this are used for development work, and cellulose acetate is sometimes chosen for this purpose because the temperatures need not be controlled very accurately and the strength of the material in the softened state is good. Heat can be applied from one side or both sides, and in a manually operated process, it will be observed that the sheet sags as it softens. Then with further heating the sheet tightens up until it is perfectly flat. At this point it is nearly ready for forming, but it is usually better to allow another 15 or 20 sec before applying the vacuum.

Equipment for large-volume production is much more sophisticated than the laboratory-type machine just described. For packaging containers, the sheet is generally rollstock and is fed into the machine by chain-mounted clamps, which grip the edges and carry it through. There are sheet-fed machines, usually rotary, but they are mostly used for non-packaging operations.

Heat is applied to both sides of a sheet electrically by quartz lamps; tubular steel rods; glass, ceramic or emitter strip panels; or calrods. A critical point is the distribution and location of these heaters so that the plastic web is uniformly heated. The heated web is then carried over a mold or molds and forced to conform to the mold shape by the means described above. Some materials such as expanded or foamed plastics require matched molds, since the sheet wants to continue expanding when it is heated, and it is necessary to confine it between the male and female parts of the mold to maintain the shape.

There are materials that can be heated by pressing against a porous hot plate with air pressure, while the edge of the mold is pressing against the plastic. This process is called "trapped sheet" forming. When the plastic has softened, the air pressure is reversed so that the sheet is forced down into the mold.

Pressure forming with a vacuum assist is much faster than vacuum forming, as the latter is limited to 14.7 lb (0.1 MPa) of atmospheric pressure to do the work, whereas compressed air can be many times this amount. Nearly all the machines used for high-production work are pressure formers. After the piece has been formed over the mold, cold air may be blown over it to speed cooling. Some formers find that a vapor spray is more efficient than air for cooling. The part is then separated from the mold by blowing it off or with knockout pins or other mechanical devices. The web is still supported between the tenter chains and carried to the next station for trimming. A steel rule die or a clicker die crush-cuts parts from the web. The size and spacing of this cutting die must allow for subsequent shrinkage, as the sheet is still warm at this point. The skeleton of the web is then wound up on a reel, while the parts are conveyed to the packing station or the next process. In commercial thermoforming companies, the scrap web is generally ground and reused immediately to reduce costs. Product companies also can return their scrap to formers for reuse.

Preformed "blisters," such as those made by the above processes in commercial thermoforming companies often are used by packagers to mount products on a printed card to hold a solid product for store display (see Figure 8.28). Preformed and deep-drawn cups and trays also are used for solid

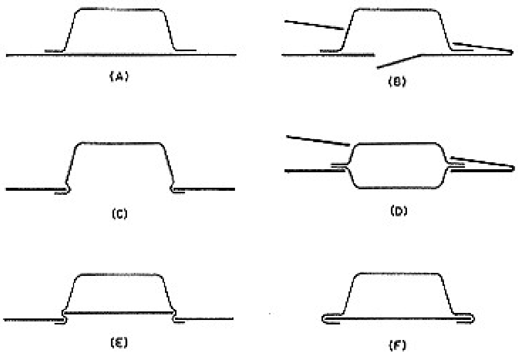

Figure 8.28.
Ways to attach transparent blisters to printed cards include (A) heat-seal flange to coated card; (B) folded card with die-cut hole for blister; (C) snap-fit (product snaps into blister, which in turn snaps into display card); (D) double blister in folded card (product appears to float in space); (E) double undercut (cutout from card serves as filler piece); (F) folded-edge blister make tracks to slide on and off the card for easy opening and reclosability.

and semisolid or liquid products, generally foods, while compartmented trays are used for tools, kits, assortments, and medical devices. There are special machines, both in-line and rotary, that feed, fill, and seal such containers with heat-sealed or snap-fit plastic lids.

But "blisters" also can be made on packaging lines located in a product plant for form-fill-seal packaging of solid, semisolid, or liquid products—foods, nonfoods, and medications. This type of machine generally runs a narrow web of sheet plastic just wide enough to make from one to four or more packages abreast. The containers can be round, but more often are rectilinear, which reduces scrap. The web is heated in a small in-line compartment by one of the means described above and formed trays are filled with product and sealed with a continuous film web. The finished containers are crush-cut from the web, which is rewound for return to the sheet manufacturer. Such equipment can be intermittent or continuous in motion, depending on product volume requirements.

Mold Design

Thermoforming can be accomplished with a male or a female mold, a pair of matched molds, or by means of a female die and a "plug assist," a male device similar to but not usually as closely shaped as a male matched die. The plug assists in production machinery are made of aluminum and cooled or warmed as necessary to avoid warping or chilling the plastic sheet. Usage depends on the part design, the type of plastic, and the requirements of the finished piece. However, today, vacuum, air pressure, and a plug assist generally are used together in most thermoforming (see Figure 8.29).

A female mold will give better detail to the outside surface, which is in contact with the mold and generally is used for deep draws. Female molds generally give better material distribution, too, and cool faster. The greatest thinning will take place at the greatest central depth of a female mold, especially near the corners. The heaviest and strongest sections will be near the outer flange. A plug assist helps even plastic distribution in this type of mold and is used for all deep draws.

With very large parts, a pressure-bubble vacuum snap-back process may be necessary. Here the hot sheet is sealed over a female mold and pressure is introduced, forcing the sheet to balloon. Then, a plug assist along with vacuum in the female mold snap the sheet back into the mold to shape it. In large-part or thick-sheet molding, the inner vacuum may be supplemented with a constant air pressure in an outer plenum.

Male mold forming, also called "drape forming," often is preferred where tolerances are critical on the inside of the part and where bottom strength and thickness is needed. A male mold must have at least 3 draft or taper. More than 3 may be required on very wide pieces or if the shrinkage rate is

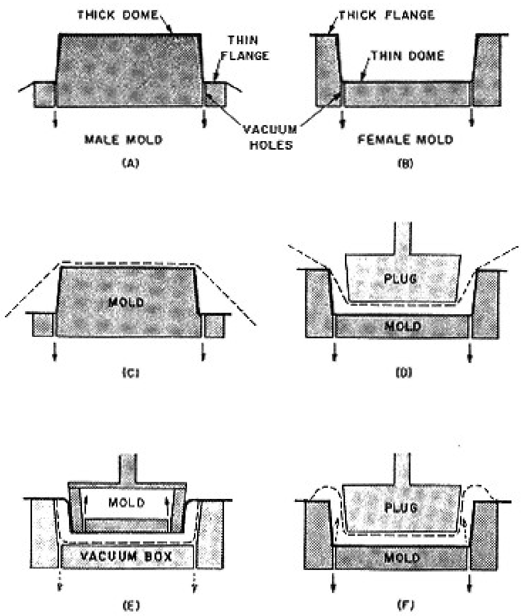

Figure 8.29.
Thermoforming techniques include: (A) male mold; (B) female mold; (C) male mold with vacuum; (D) female mold with plug assist; (E) snap-back forming (pulls heated plastic into vacuum box then forces it back up against a male mold); (F) billow forming (compressed air stretches the sheet upward, after which a plug carries it down into the mold as a vacuum pulls it into place).

high (no draft is needed for female molds, since the part pulls away from the mold as it shrinks).

Depth of draw in a male mold, generally, should be less than the width of the cavity, to avoid excess thinning, although depths of 3:1 or more have been routinely achieved with some parts and some plastics. Use generous radii wherever possible, especially where thinning is likely to occur. A radius should be at least twice the thickness of the starting material. Most thermoforms have to be trimmed regardless of which type of mold is used. Trimming can be by hand or punching dies, which operate while the part is in the mold or separate.

Where a flange is necessary around the outside edge of the drawn shape for sealing to a card, use it to advantage for stiffening. Ribbing will strengthen flat panels and wide spans, as well. For vacuum forming, the mold has to resist stresses up to only 14.7 psi (0.1 MPa), which is normal atmospheric pressure. Pressure forming, on the other hand, may develop forces up to 300 psi (2.1 MPa).

Materials for making thermoforming molds are many and varied. Wooden molds can be used for developmental work, but will soon get scorched from the heat of the plastic. Plaster of paris often is used for short-run molds, but is not very durable, being inclined to chip and crack with prolonged use. Epoxy resins sometimes are used for forming light-gauge material up to 0.030 in. (0.8 mm), but poor thermal conductivity makes them unsuitable for heavyweight forming. Sprayed metal molds are costly, but give perfect detail with no shrinkage. In this process, zinc-aluminum wire is fed to a special spray gun, melted, and blown out as a very fine spray. It freezes instantly on the pattern with no significant amount of heating of the sprayed surface. In this way, coatings up to 0.5 in. (12.7 mm) thick can be built up. Cast aluminum is best for large-scale production, and the walls are usually made about 0.5 in. (12.7 mm) thick. Sometimes molds are made from beryllium copper or brass. All of these metals will dissipate heat rapidly and give a high rate of production.

Vent holes must be provided in sufficient number and in the right places to draw the plastic down into every crack and crevice in the design, particularly in the corners. The holes should be about 0.016 in. (0.41 mm) in diameter for thin materials, and about 0.031 in. (0.8 mm) for heavier gauges. Smaller holes may be required for PE because hole marks show up more in this material. Deep sections in the mold should have more holes than shallow, especially when the deep and shallow areas are adjacent. They can be as close as 0.5 in. (12.7 mm) apart, if necessary. Cooling is provided by cored or drilled holes in the mold. These must be placed so that they do not interfere with the air vent holes and, of course, must be waterproof. If copper or stainless steel tubing is used for cooling, it should be at least 0.5 in. (12.7 mm) in diameter and spaced 2.5 in. (6.4 cm) apart. Some sections of the mold may require more cooling than others, but this can be determined only with experience.

For some materials, such as impact styrene, the mold should be kept fairly warm, around 150 F (65.6 C) to avoid stresses due to rapid cooling that may cause warpage. If necessary, undercuts can be handled in several ways. Split sections can be removed from the mold to release the part. Hinged sections can fold out as the part is removed. Knockout pins can be incorporated for shallow undercuts, or cam-actuated sections can be pulled out of the way for releasing the piece. Compressed air often will release a formed part if the undercuts are not too deep. The surface of the mold should be sandblasted to allow passage of air between the plastic and the mold during the forming operation, as well as for removal of the piece from the mold. With all of the above techniques, thermoforming of consumer packages has become very sophisticated with very few limits, today.

Skin Packaging

An offshoot of blister packaging is "skin packaging." In this process the sheet (or film) is heated and drawn down over the product, instead of preforming a blister to contain the item. The cards are preprinted and generally coated with a heat-activated sealant and also are pierced with needlepoints so that a vacuum can be pulled through the card stock. As the film is sucked down around the product items, it quickly adheres to the card, holding the pieces firmly in place. Cycle time for skin packaging is about 40 secs.

Generally, thin films are used, around 5 mils (128.2 m) or less in thickness, so that skin packaging is basically less costly than blister packaging, unless the card is much larger than the item. A film must cover the entire card in skin packaging, whereas a blister needs to be only slightly larger than the object it contains.

There is a tendency for the cards to warp, owing to the shrinkage of the film as it cools. Not much can be done to eliminate this, although it can be minimized by zone heating and by using a heavy weight of paperboard for the card. Vinyl films generally are preferred, but LDPE and PP can be used with uncoated paperboard if the films are treated by flame or corona discharge to oxidize the surface so that it will adhere to the board. With these films, perforating the board, if uncoated, usually is unnecessary as there generally is enough porosity for pulling the vacuum through the board. Where great toughness is required for heavy items or those with sharp edges and points, tough ionomer film is used for the skin. It is considerably more expensive than either PE, PP, or PVC, but can withstand abuse.

Collapsible Tubes

The collapsible plastic tube was introduced into this country by Bradley Dewey when he acquired the rights to a European process in the early 1950s. This is an extrusion molding method in which the sleeve (body) is extruded while the shoulder and neck are constructed separately and adhered to the sleeve by one of several techniques.

In 1971 a laminated barrier sleeve with up to 10 layers of plastic, foil, paper, and various adhesives was introduced by American Can Co. (now American National Can Co., Chicago) and used by Procter & Gamble Co., Cincinnati, for tubes of its Crest toothpaste. Since then, a number of improvements and new concepts for attaching the head of the tube to the sleeve have appeared.

In the United States, though, one of two methods, Strahm or Downs, are used. In both processes, the sleeve is extruded as thin-walled tubing with a wall thickness of 0.014 to 0.018 in. (0.36 to 0.46 mm) and corona treated for subsequent printing. The tubing is then cooled on a chilled mandrel with cold water and cut precisely to length with a rotary knife. All tubes are printed by the dry-offset process with or without added metallic hot stamping. Cut sleeves can be printed before or after heading.

In the Strahm process, the sleeve is inserted into the cavity of an injection (heading) mold and the shoulder piece is injected around it, fusing the two parts together at the corner of the shoulder. Melt temperature is usually more than 500 F (260 C) to insure a solid bond with the sleeve. The tube remains in the closed tooling until it cools and then passes to a trimming station for removal of a sprue on the head.

In the Downs process, the sleeve is inserted into a punch that cuts a 0.125-in.-thick disk (3.2 mm) from a molten strip of plastic. This disk immediately adheres to the inner diameter of the sleeve, which is transferred on its male tool to a second station where a female die forms the tube head by compression molding, a scrapless process that eliminates the sprue-removal step in the Strahm process. A variation of this technique is a Swiss method from Karl Magerle AG in which a "doughnut" of molten plastic is injected into the female die before it closes around the male sleeve.

The preprinted 0.013-in. (0.33-mm) laminated sheet is created in large rolls that are slit to the right width and folded around a mandrel to form a continuous sleeve. The critical area is the overlap of the web. Radiofrequency (RF) sealing the lap under pressure extrudes some plastic over this bonded surface to create an assured barrier seam. To complete the barrier closure at the tube head, a molded insert of polybutylene terephthalate (PBT) or urea is positioned on the head of the male sleeve tool and bonded in place by the injected head plastic, which bonds over the insert to the laminated sleeve. Both urea and PBT are barriers to oxygen and flavor constituents and resistant to injection-molding temperatures and pressures.

Since this innovation, other slightly different methods for bonding laminations have been developed. However, the most striking change has been the availability of EVOH barrier plastic, which has made an all-plastic high-barrier tube possible. The Japanese and others have created conventional coextruded sleeves and also blow-molded barrier tubes that are trimmed at either end to form a sleeve. Costs can be premium, but these structures have been used to meet stringent packaging requirements.

Plastic tubes generally are made of flexible LDPE. However, other materials such as HDPE, PVC, and PP are used if better adapted to product or usage. Tubes frequently are coated after printing with clear epoxy resin for gloss or to protect the product and printing.

Originally, standard tube dimensions and tools were those of the European system. Now, however, threaded finishes and body sizes conform to the standards used by the metal tube industry as far as possible, and the same closures, fitments, and handling equipment can be used. Only the method of sealing the bottom ends differs.

Here, the simplest method is to clamp the tube end between cold jaws and then pass the protruding portion, about 0.125 in. (3.2 mm), between radiant heaters until the plastic melts and forms a bead. Heated and coated seal bars and ultrasonic sealing also are used to close tubes. In ultrasonic sealing, the plastic tube base is sandwiched between a steel "anvil" plate and a steel "hammer," or tool, which is caused to vibrate at very high frequencies (20,000 to 30,000 Hz) by a piezoelectric crystal. The resultant friction generates enough heat to rapidly melt the plastic surface. Regardless of the sealing method, the inner surface of the tube end must be free from product splashes, which can prevent a good seal.

Another important difference between plastic and metal tubes is the "suckback" characteristic of plastic tubes. This is both an advantage and a disadvantage. From an appearance standpoint, the plastic tube always looks full and is never wrinkled or misshapen. When it is partly empty, however, it is a nuisance because the air must be expelled each time before product can be dispensed. This can be avoided by using a stand-up type of cap, which is as large in diameter as the body of the tube. Printed copy on the tube is usually inverted to call attention to the standup feature and to make it readable when it is put on the shelf with the cap down.

Plastic Drums

Plastic drums are blow molded, at the rate of about 12 million 55-gal (208-L) containers per year in the United States. Cost of a simple, open-head 55-gal (208-L) plastic drum runs between $19 and $20 each in truckload quantities. This compares with $23 to $24 for a plain steel drum and $15 for a fibre drum with a plastic liner. But there is more to it than price. Tare weight is 23 lb (10.43 kg) for a plastic drum, 37 lb (16.78 kg) for a steel drum, and about 14 lb (6.4 kg) for a fibre container and has a definite impact on shipping costs.

Why not choose a single type of drum? It's because there are all kinds of products and shipping conditions. For example, a closed-loop distribution system using fibre drums that are shipped back, often in the captive truck fleet of either the vendor or the customer, and are simply refitted with a new liner and used again can last for a many trips. But, rough handling, long distribution distances, multiple off-loading, and handling for less-than-truckload shipments can require, at the least, a sturdier plastic drum or welded steel container. There is a place for all three.

Coatings and Coextrusion

To diminish permeation and resist scuffing and abrasion, plastic containers have been dip-, roller-, and spray-coated inside and out with various other plastics. Despite improvements in the process, the downside is still cost and the difficulty of getting complete coverage on oddly shaped containers and those with ears and handles. However, coatings have been used in instances where barrier needs warrant the cost.

The coextrusion of bottles to suit both barrier and structural needs has grown, particularly with the advent of a plentiful supply of recycled plastics. Coextrusion blow molding was first developed in the 1970s by Japan,s Toyo Seikan Kaisha and Toppan Printing, which developed their own coextrusion die heads. Today, the core of such containers is usually a thick structural layer of recycled plastic and, when necessary, a thin layer of a high-barrier material to prevent permeation of moisture and/or gases. Outer and inner layers of virgin material create a good appearance and satisfy regulations with respect to contact surfaces for foods and pharmaceuticals.

Typical barrier layers are PVDC, EVOH, nylon, and nitriles. Outer and inner layers also can provide both barrier and structural strength when made from HDPE, PP, PVC, PS or PC, according to the properties needed (see Table 8.2 for details on plastic properties and costs). Coextrusion is a complex operation. Since layers must be extruded and bonded together, it is desirable to select resins with similar viscosities and melt temperatures. To make this possible, special adhesives are essential and their selection is of critical importance.

Decoration

Various printing processes are used for decorating plastics. Flexographic printing is used for films, offset printing for bottles, jars, and collapsible tubes, and silk-screen printing for small quantities of rigid parts where a luxury effect is desired. For bright metallics, hot stamping offers a good method, and this technique can be used for colors as well.

Testing

There is a misconception that plastics are unbreakable. Although the amount of abuse that plastic containers can withstand is considerable, they are far from indestructible. Therefore, it is important to test new containers adequately so that the proper protective packing can be provided. When stacked in the warehouse, plastic containers cannot support the same amount of top loading as metal or glass containers so their shippers may require additional vertical, internal supports.

Impact resistance is generally tested by dropping individual filled bottles on a hard surface. Bottles should be filled with the actual product for reliable results, and filling should be done 24 hours before testing. Freshly filled bottles should not be used for testing because it takes a certain length of time for the inside surface to reach a state of equilibrium with the contents. A typical bottle will withstand drops of 6 to 8 ft (1.8 to 2.4 m) without failure, and when rupture does occur it is usually at the pinch-off. For details about container testing see Chapter 18, Preshipment Testing.

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Chapter 9— Glassware

History

Glass is one of the oldest substances known, and a material similar to glass of volcanic origin was used for arrowheads during the Bronze Age. In the first century A.D., Pliny wrote of sailors who used blocks of soda from their cargo to make a fireplace on the beach and discovered that the soda fused with the sand to form glass. It is believed that the Egyptians were using glass as early as 3000 B.C. The blowpipe is known to have been used in Sidon during the first century B.C. for making hollow glass articles, and by the third century of the Christian era, articles of glass were in fairly common use in Roman households. The commercial success of the Venetian glassblowers in the sixteenth century is well known, and the term *flint glass* refers to the very pure silica in the form of flint used by these artisans of Venice.

Around 1870, the shop system of making glass containers was introduced in the United States. This consisted of a team of seven people: three skilled workmen and four boys. The first man on the team would remove a lump of molten glass from the furnace on the end of his pipe and partially blow it. A boy called the "mold tender" would open the mold so the blower could put the glass into the mold and inflate it with pressure from his mouth. The pipe was then cracked off and the glass was taken by the "snapping-up boy" to the finisher, who shaped the neck and the lip with tools. The "carrying-in boy" then took the ware to the lehr (oven) while a "cleaning-off boy" prepared the blowpipe for the next gathering.

Two blowers would alternate in filling the mold, or one would pre-blow and swing while the other did the final blowing. Since the neck was made last, it was called the "finish," and even today, although many machines make it first, the top of a glass container is still called the finish. A forerunner of today's glass containers, the milk bottle, was invented in 1884 by a physician who was concerned about the delivery of safe, clean, fresh milk.

Mechanization, first introduced on a large scale in 1892, permitted some of the skilled workers to be replaced by unskilled operators. In 1896 the Atlas Glass Works was using semiautomatic machines in regular production for wide-mouth jars.

The first fully automatic machine was designed and built by Michael J. Owens in 1903, while he was working in the Toledo, Ohio, plant of Edward D. Libbey. In this machine, a “blank” mold was dipped into the tank, molten glass was sucked into the mold, and the bottom was trimmed off to give the correct amount of glass to make one bottle. This “parison” was then transferred to another mold for final blowing. By 1917 there were 200 of these machines in operation around the country.

Meanwhile, the Hartford-Empire Company was perfecting its “IS” (individual section) blow-and-blow (B&B) machine, and the principle of dropping a gob of glass into the mold from the top started to replace the Owens method of feeding from the bottom in most glass plants (see Figure 9.1). IS machines are made up of four to sixteen straight-line sections, which contain a set of blank molds and forming molds. By 1925 production on the two types of machines was nearly equal.

The efficiency of the in-line IS machine has been further increased with double-, triple-, and quadruple-gobbing techniques in which multiple containers are produced in each machine section every cycle. Double- and triple-

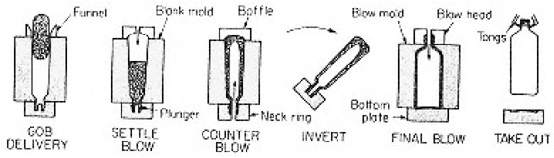

Figure 9.1.
This schematic diagram shows successive operations performed by an IS machine in making a bottle by the blow-and-blow process. The gob of hot glass comes down a chute into the blank mold and is sucked down over the plunger by vacuum. The baffle comes down on top, the plunger is withdrawn, and compressed air is introduced to blow the glass to the shape of the blank mold. The mold opens slightly to allow the surface of the parison to reheat by flow of heat from the interior. The parison is inverted to bring the neck ring on top, and the blow mold closes around it. Compressed air forces the glass against the blow mold, giving the container its final shape. The mold opens and tongs pick up the bottle by the neck ring, placing it in a programmed location on a conveyor that carries it through the annealing lehr.

TABLE 9.1. 1995 Markets for Glass Containers.

Market	Percentage
Beer	41
Wide-Mouth Food	32
Narrow-Neck Food	7
Beverages	6
Wine	5
Liquor	4
Drugs and Chemicals	3
Toiletry & Cosmetic	2

gobbing are most common. However, containers up to 2.1 qt. (2 L) can be blown in single-gobbing machines, while quadruple gobbing is limited to 12-oz (355 ml) sizes. Speeds also have been increased by adding a second blow mold for each blank mold. B&B molding generally is used for narrow-neck bottles.

A variant is the rotary Miller press-and-blow (P&B) machine used for wide-mouth jars. In this technique, the finish is formed last in the parison. In P&B machines, a plunger presses the glass gob into the blank mold, which insures a very uniform wall thickness. As much as 10 percent less glass can be used because of the better distribution.

Since such machines start with a solid blank, there is no baffle seam and, consequently, less breakage from thermal shock than with containers made by the B&B method. There are limitations in design, however, because the blank must be stripped from the parison, and at least a 2 taper must be provided from the neck ring downward.

Glass containers have seen dramatic changes in recent years. Virtually all captive manufacturers have left the business and mergers have reduced the number of major North American manufacturers to four. In addition, market share has been eroding for more than 20 years as the container has been replaced by plastic, especially polyethylene terephthalate (PET), containers. As a result, unit shipments declined to 38 billion in 1995, a 5 percent drop compared to 1994, according to U.S. Department of Commerce figures. Sales were just over $5 billion and divided among numerous markets, the strongest being beer (see Table 9.1).

Advantages and Disadvantages

Glass has been—and will remain—an important packaging material for a number of products because it is strong, durable, transparent, and chemically inert. Pleasing to the eye, it evokes an image of quality and allows the consumer to see the product. Glass is impervious to transmission of gases and products and, therefore, is used extensively to contain delicate flavor and perfume essences. It also is proof against the harshest acids and bases known to chemistry (except for hydrofluoric acid, which is actually used to etch glass).

Glass containers also can be used in microwave ovens and served at the table without the contents being transferred to another receptacle. All colors of glass—flint, green, opal, and amber—are equally transparent to microwave energy. It is strongly recommended that closures be loosened before the containers are put into the oven for heating to prevent pressure buildup. But even when it is on tight, tests indicate that the cap will blow off before the container explodes.

Glass is made from relatively inexpensive domestic raw materials, but the process is rather energy-intensive.

Despite lightweighting efforts, glass is still heavier than a comparably sized plastic or aluminum container, which means it is more costly to transport. Breakability is another negative although new coatings that reduce abrasion and, therefore, breakage are being pursued.

Chemistry of Glass

Glass is not a crystalline material in the usual sense of the word. Although the molecular structure is believed to be orderly in the shorter ranges (2 to 20 Å), it is probably disordered in terms of long-range crystal lattices. The constituent crystallites are very small, ranging in size from 0.1 to 1.0 m (0.0000039 to 0.000039 in.). Since by definition, a crystal is a strict repetition of identical units and glass does not conform to this description, it is more realistic to consider it a congealed liquid. Its structure is more dependent upon its thermal history than upon the chemical composition, but it is worth noting that the less sodium oxide, the stronger the glass, although only by a small percentage. The principal ingredients of glass are sand, soda ash, and limestone.

The sand is almost pure silica, and the soda and lime are usually in the form of the carbonates $NaCO_2$ and $CaCO_2$. There also can be traces of other materials, such as lead, which gives clarity and brilliance, but is inclined to yield a relatively soft grade of glass. Alumina (Al_2O_3), however, often is used to increase hardness and durability. The formulation of the glass can be adjusted for specific purposes. Thus, if resistance to chemical action is especially important, less sodium and more aluminum compounds can be used; if alumina supplies one-eighth of the alkali content, the glass will be highly resistant to chemical attack.

Magnesia also is a valuable addition for chemical durability, but it has a tendency to form "flakes" in solutions. To reduce seeds and blisters, fining agents such as salt cake (Na_2SO_4) and arsenic (As_2O_3) often are used. Since lower temperatures are possible if certain ingredients are added and machine operators like to work with glass below 1,200 F (649 C), the glass is usually formulated this way for better machinability. If breakage from thermal shock is a problem, it is possible to use high-silica, low-alkali combinations, but these may lead to "cord" problems (strains not relieved by annealing).

In the manufacture of glass, the sand, soda ash, and limestone are mixed with glass fragments, or "cullet," to help in the melting and fed into the furnace. The soda ash melts first, acting as a solvent for the sand, which otherwise would require a much higher temperature to become molten. A gas flame coming from the side above the melted glass keeps the material in the tank between 2,600 and 2,900 F (1,427 and 1,593 C). Currents formed in the molten glass by the bubbling of escaping gases mix each batch of fresh ingredients uniformly with the material already in the furnace. The steady flow toward the opposite end, where gobs are drawn off for the machines, also helps generate currents which aid in the mixing (see Figure 9.2).

Although glass is fairly inert and used to contain strong acids and alkalies, as well as all types of solvents, it has, nevertheless, a definite and measurable chemical reaction with some materials, notably water. The sodium is rather loosely combined with the silicon and is leached from the surface by plain water. In one year, distilled water in a flint glass container will pick up 10–15 ppm of NaOH, along with traces of other minerals in the glass. The addition of about 6 percent boron to form a borosilicate glass reduces this leaching action so that only about 0.5 ppm would be dissolved in one year.

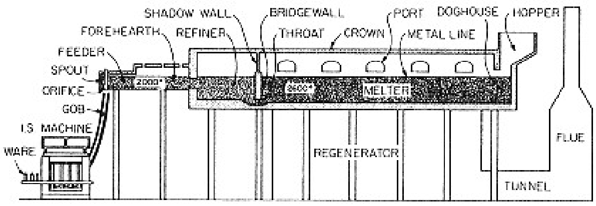

Figure 9.2.
Glass tank for melting container glass has gas flames from side ports that pass across the surface and into a regenerator on the opposite side. Every 20 min the direction of firing is reversed to take advantage of the heat that accumulates in the regenerators on each side. The molten glass is mixed by currents that develop in the melter. Materials are charged in at the hopper end, move from right to left in the illustration, and then pass through the throat into the refiner. Impurities that float on top are held back by the bridge wall. Several forehearths lead off from the refiner, where the temperature is reduced and the formula adjusted. The glass then passes into the feeders, where it is pushed through an orifice and cut off by shears into uniform gobs, ready to be formed into containers.

When glassware is stored for several months where fluctuations of temperature and humidity cause condensation, salts are dissolved out of the glass, a condition called "blooming." Moisture tends to run down the inside as well as the outside of the ware, and it is common to find a heavier deposit near the bottom of the container. The bloom sometimes interferes with labeling and decorating operations. It can be removed with an acid wash, but it is best to work with freshly made ware whenever possible to avoid such complications. If the alkali in the glass may affect the product contents, soaking in plain water will remove most of the bloom from the surface. Adding some dilute acid or heating the water will speed up the process.

Some manufacturers offer a special sulfur treatment, and the sodium sulfate which is formed on the surface is much more resistant to attack by water and acids. It does not, however, make the glass any more resistant to alkaline solutions. Borosilicate glass, designated as Type I in the *United States Pharmacopoeia* (USP), is substantially more resistant to attack by alkalies than regular glass, although resistance varies with the kind of alkaline material [1]. It is about ten times as resistant to acids (see Table 9.2).

Colors

Some colors of glass, such as amber, green, and opal, are readily available for containers (see Table 9.3). Full tanks of these colors are maintained at several glass plants. Other colors are available only if the orders

TABLE 9.2. Types of Glass for Pharmaceuticals.

Type	General Description	Type of Test	Size (ml)	Limits ml of 0.20 N Acid
I	Highly resistant, borosilicate glass	Powdered Glass	All	1.0
II	Treated soda-lime glass	Water Attack	100 or less Over 100	0.7 0.2
III	Soda-lime glass	Powdered Glass	All	8.5
NP	General-purpose soda-lime glass	Powdered Glass	All	15.0

The description applies to containers of this type of glass usually available.

Size indicates the overflow capacity of the container.

Source: Copied with permission from *USP XXII.*

TABLE 9.3. Coloring Agents Used in Glass.

Color	Agent
Red	Cuprous or cupric oxide, cadmium sulfide
Yellow	Ferric oxide, antimony oxide
Yellow-green	Chromic oxide
Green	Ferrous sulfate, chromic oxide
Blue	Cobalt oxide
Violet	Manganese
Black	Iron oxides in large amounts
Opal	Calcium fluoride
Amber	Carbon and sulfur compounds

are very large. However, a method has been developed for adding the coloring material in the forehearth, so that much smaller orders of special colors can be processed and made available to users who could not justify a full tank of special glass. (The forehearth is shown in Figure 9.2.)

In addition to the decorative use of colored glass, certain colors are effective in protecting a product from the effects of sunlight by screening out some of the harmful rays. Amber glass is required by the USP to screen out light in the range of 2,900–4,500 Å (0.029 to 0.045 m). Flint blocks the rays at 2,900–3,200 Å (0.029 to 0.032 m) (far ultraviolet), and emerald green is effective against visible violet-blue light at 4,000–4,500 Å (0.04 to 0.045 m) (see Figure 9.3).

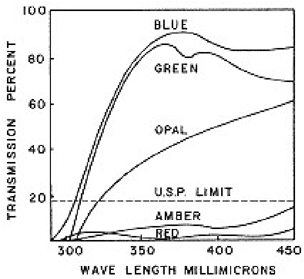

Figure 9.3.
Colored glass will protect the contents of a bottle from light in varying degrees, depending on the color. In the critical ultraviolet region, only amber and red glass are really effective.

Mechanical Properties of Glass

The strength of glass has little relationship to its chemical composition, one type of glass being very much like another. The condition of the surface, however, greatly influences its tensile properties. The theoretical tensile strength of glass is greater than 2×10^{6} psi (137,900 MPa). The effective strength of annealed glass is between 3,000 and 8,000 psi (20.7 and 55.2 MPa). Tempered glass (the type used for automobile windows) has a high compressive stress in the outer layers with tension in the interior and strength between 12,000 and 40,000 psi (82.74 and 275.8 MPa). New chemical treatments have produced strengths up to 200,000 psi (1,379 MPa). A smooth surface on a bottle, just as it comes from the mold, will withstand stresses of 100,000 psi (689.5 MPa) or more. When the surface becomes scratched or bruised even the slightest bit, however, more than half the strength is lost. By the time it reaches the store shelf, the strength may be as low as 3,000 psi (20.7 MPa).

An understanding of "notch sensitivity" of brittle materials may help explain this great loss of strength. Stresses are concentrated at the tip of a notch in any material, but with ductile materials the tip of the notch yields, the sharpness of the notch is blunted, and the stress concentration is reduced so that the fracture does not go any farther. In fact, most ductile materials "strain harden" at the tip of the notch sufficiently to offset the increased stress at that point. With brittle materials such as glass, however, the stresses frequently exceed the strength of the material at the tip of the notch. A crack develops, and failure is instantaneous.

It is known that micro-cracks exist on all glass surfaces as a result of handling in manufacturing and distribution in amounts varying from 1,000/cm^2 (155/in.^{2}) on fine plate glass to more than 50,000/cm^2 (7,750/in.^{2}) on commercial-grade glass. Although these micro-cracks may be small, if sharp enough, their stress-concentrating effect can be considerable. This effect is proportional to the square root of the ratio of the notch depth to the notch tip radius. Thus, a sharp notch only 1 μm (0.000039 in.) deep could cause failure.

Various coatings can be applied to the ware before it enters and/or as it exits the annealing oven to protect the surface and preserve as much of the original strength as possible. The coatings do not add strength directly, but act mainly as lubricants so that contact between bottles or between bottle and machine is much less likely to damage the surface (see Tables 9.4 and 9.5.)

If allowed to cool too quickly, strains will be set up in the glassware, making it more susceptible to breakage. For this reason, bottles and jars are al-

TABLE 9.4. Properties of Coatings for Glass Containers.

Property	Silicone	Metallic Oxide	Wax	Resin	Sulfur
Insoluble in water	Yes	Yes	Yes	Yes	No
Wettable	No	Yes	Yes	Yes	Yes
High film strength	No	Yes	Yes	Yes	No
Easy to apply	Yes	No	Yes	Yes	Yes
Visible on surface	Yes	Iridescent	Yes	Yes	No
Difficult to label	Yes	No	No	No	No
Protects when wet	Yes	Yes	Yes	Yes	No
Nontoxic	Yes	Yes	Yes	Yes	Yes

Hot or cold water.

ways put through an annealing lehr, where the temperature of the glass is raised to 1,000 F (537.8 C) and held at that level for 15 min. Then cooling very slowly to room temperature relaxes any strains, which may have developed from contact with the molds and conveyors.

Occasionally, there are strains known as cords, which are not relieved by the annealing process. These are caused by poor mixing in the melting tank, resulting in a variation in the composition of the glass. This produces a weak container which may break spontaneously. Such strains can be detected with a polariscope by cutting sections and examining the colored bands produced by the polarized light. They are usually considered critical defects (see Table 9.6).

TABLE 9.5. Lubricity of Coatings for Glass.

Coating	Maximum Coefficient of Friction	Angle of Repose (degrees)
Silicone oil	0.26	14
Polyethylene	0.27	15
Glyceride	0.28	16
Polyoxyethylene	0.29	17
Stearate	0.30	18
Metallic oxide	0.40	24
Uncoated glass	0.84	40

TABLE 9.6. Classification of Glass Container Defects.

Critical Defects

Birdswings and spikes are long, thin strands inside the bottle, which would probably break off during filling.

Overpress creates a rim extending up from the inside edge of the finish, sometimes with a sharp ridge.

Filaments are hairlike strings, not infrequently found inside a bottle.

Split is an open crack starting at the top of the finish and extending downward.

Checks are small, shallow surface cracks.

Hot checks are generally straight lines.

Groups of checks at the top of the finish are called a crizzled finish.

Pressure checks occur near the seam and may be small or run the full length of the bottle.

Bruise checks often show up at the shoulder or heel.

Mold checks are deep and run from the bottom up the sides.

Disk checks occur on the bottom from contact with the transfer disk in the molding operation.

Panel checks are found on flat areas.

Unfilled finish is a wavy top surface or a dip, usually right above the start of the thread. More rarely, the thread or the transfer bead is not filled out.

Freaks are odd shapes and conditions that render the container unusable.

Bent or cocked necks are a common defect.

Poor glass distribution involves a thin shoulder, slug neck, choke neck, hollow neck, heavy bottom, or slug bottom. A slug is a heavy spot, most often found at the parting line.

Finish marks are lines on the sealing surface, sometimes called shear marks.

Soft blister is a thin blister, usually found in or near the sealing surface. It can, however, show up anywhere on the bottle.

Cracks are partial fractures, generally found in the heel area, but sometimes occurring at the shoulder.

Cord is a strain, which is not relieved by annealing.

Pinhole is any opening causing leakage. It occurs most often in bottles with pointed corners.

Chipped finish is where pieces have been broken out of the top edge in the manufacturing process.

Fin is an extended seam on the top surface or down the side at the parting line.

Major Defects

Stone is a small inclusion of any non-glass material.

Rocker bottom involves a sunken center portion of the bottom.

Mismatch is where one-half of the finish is shifted to the side or upward from the other half, or the finish is “set over” from the rest of the container.

Out-of-round finish is one that is pinched, flattened, or oval.

Flanged bottom is where a rim of glass exists around the bottom at the parting line.

(table continued on next page)

TABLE 9.6. (continued).

Minor Defects
Sunken shoulder is one that is not fully blown or sagged after blowing.
Tear is similar to a check, but opened up. A tear will not break when tapped, a check will.
Washboard is a wavy condition of horizontal lines in the body of the bottle.
Hard blister is a deeply embedded blister that is not easily broken.
Dirt is scaly or granular nonglass material; also oil, carbon, dope, rust, graphite, or other foreign substances.
Heeltap is heavy glass on one side of the bottom.
Mark is composed of fine vertical laps. Oil marks are the result of oil accumulation on the molding equipment. Carbon marks come from the feeder or from mold dope.
Droplet is a small projection of glass, usually near the parting line of the finish, caused by chipped neck rings.
Neck ring seam is a bulge at the parting line between the neck and the body.
Long neck is a stretched-out neck resulting from the bottle being too hot when it was picked up.
Struck is what happens if bottles touch while still soft. They may stick and, in pulling apart, leave a rough spot.
Seam mark from the blank mold may not correspond with the mark made by the joint of the finishing mold. This is not a defect unless it is very large or unsightly.
Seeds are small bubbles in the glass.
Cold appearance, also called cold mold, is a wavy condition on the surface of the bottle.
Wavy bottle is an irregular surface on the inside.

Design Considerations

The shape of a container will have a very important influence upon its strength. A sphere is the strongest; a cylinder is next; and a rectangular shape the poorest from an engineering standpoint. The flat panels of a rectangle will yield more readily than convex panels, particularly if the stress occurs near the middle. Therefore, the designer should provide ridges or beads to take the shock in the center. These ridges can be further strengthened by making them knurled instead of straight. Although these principles pertain particularly to square shapes, they also can apply to rounds, ovals, and other styles. Bottle strength can be increased as much as 50 percent by designing it to direct shocks where they will do the least harm.

Corners tend to be the thinnest part of a container because that's where the glass has to stretch the farthest. Bottom corners are especially vulnerable because containers are usually dumped on filling-line conveyors right-side up. This often bruises the bottoms. Corner thinness can be minimized to some degree by the shape of the parison. It is not possible to get perfectly uniform distribution of glass, however, and the shoulder and heel are usually the thinnest areas.

Sharp corners and edges should be avoided because they are difficult to make and will lead to a high incidence of defects in the finished ware. Sharp convex edges in the mold, for example, tend to cause hot checks or pressure checks in the glass. Acute concave angles require high temperature and pressure to force the glass into the corner, possibly causing cocked necks, hollow necks, or other problems. On the other hand, many decorative effects can be obtained with sunken panels, flutes, stippling, and similar design devices.

A design for a new container is worked out with the necessary allowances for headspace, weight of glass, and other such factors. The amount of headspace may be determined by the customer, depending on where the fill point is desired, or based on tests at 0 and 135 F (-17.7 and 57 C) to ensure that breakage will not occur under the most adverse weather conditions. A pharmaceutical fill is usually halfway up the shoulder, whereas a cosmetic fill is to the base of the neck (see Figure 9.4). Since the mold determines the outside dimensions of the container, wall thickness must be taken into consideration in calculating desired capacity.

Molds are made mainly of cast iron or compacted graphite. However, since several parts are involved, i.e., bottom plate; two vertically divided body mold halves; and a two-part neck or finish mold, other materials may be used to provide the required degree of thermal conductivity, hardness, and release properties. For example, neck rings often are made of a highly conductive copper-nickel-aluminum alloy, and nickel-boron imparts the hardness and release properties needed for baffles and plungers. In a coating

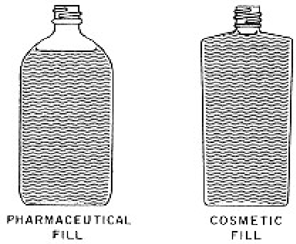

Figure 9.4.
Pharmaceutical products usually are filled to a point halfway up the shoulder. Cosmetics and toiletries often are filled to the base of the neck for a better appearance.

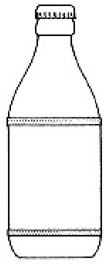

Figure 9.5.
Shock bands will reduce breakage by providing raised areas at the shoulder and base to take impact stresses. Stippling these bands also will help limit the effects of bruising in this area.

form, nickel-boron also is used to protect mold-to-mold contact surfaces and lengthen mold life, usually 2 to 3 million pieces before reconditioning is needed.

As long as gob weight and bottle height is considered, it is possible to mix various body and finish molds. In fact, it is often possible to substitute finish molds that are a few millimeters larger or a size smaller or of a different type for use with the same body molds. It's also possible to switch to a new neck or body shape by combining a new blow mold with an existing blank.

For a new look, blow molds can be texturized to modify the surface of the container or engraved to add beads, logos, or other geometric designs to create decorative optics.

The cost of a set of molds for a private mold design will be about $5,000 per cavity. This will translate into a bill of $30,000 to $40,000. So mold cleaning and repair does not halt production, 50 percent more molds are ordered than would be in use at any one time. However, mold costs can be eliminated completely by choosing a stock container.

Body molds are made in two halves, which are divided in a vertical plane. In a square or oblong shape, the parting line is usually placed on diagonally opposite corners so that the mark made by the joint will be less noticeable. A raised band or bar at the shoulder and the base—if it can be worked into the design—provides contact points on the filling line and greatly increases the durability of the container (see Figure 9.5).

The bottom plate may carry a manufacturer's symbol called a punt mark or, in the case of private molds, the customer's name. A plant number also may be added if the manufacturer has several plants and sometimes the date

Figure 9.6.
The bottom plate may include a double dot pattern forming a binary code to identify the mold that produced the container. Also visible is the knurled or stippled pattern commonly used on container bottoms to minimize the thermal shock of contact between container and lehr belt.
(Source: AGR International, Inc., Butler, Pennsylvania, used with permission.)

of manufacture is indicated by the last two digits of the year. At least one container maker uses ink-jet printers to apply more precise manufacturing codes.

The bottom plate also may carry a mold number or binary code of raised double dots to identify the cavity that made the container and serve as an aid in tracing defects (see Figure 9.6) [2]. Today, however, the mold code is more likely to be found on the heel of the container in the form of a series of raised dots (see Figure 9.7) [3]. In today's automated facilities, the heel code allows containers to be selected or rejected based on their cavity numbers through the use of a Heel Code Reader. For proper reading, dots should be positioned a minimum of 5/32 in. (4 mm) from the parting line or any decoration [4]. It also should be noted that heel codes may not be compatible with certain shapes.

It is good practice to stipple the bottom plate, at least that part that forms the container bottom that will be in contact with the conveyor. This also minimizes the thermal shock of contact between the container and the lehr belt. A minor disadvantage of stippling the bottom is that the crevices may pick up dirt on the filling line.

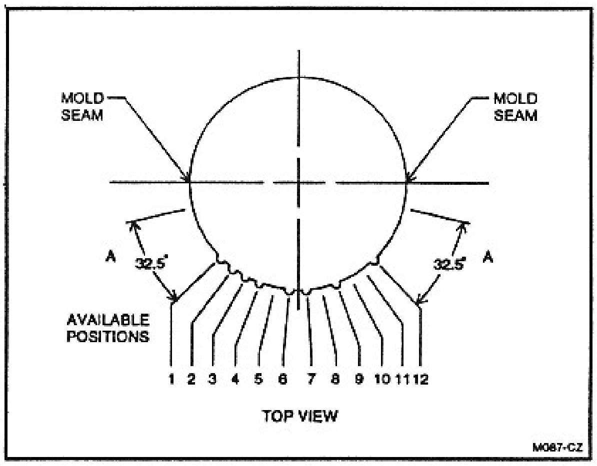

Figure 9.7.
A series of raised dots on the heel of the container is the preferred way today to identify the mold it came from. The AGR Heel Code system, one of several in use by the glass manufacturing industry, uses a maximum of eight out of twelve possible dot positions with the first and last always used. Selected dot combinations represent numbers 1 through 127. (Source: AGR International, Inc., Butler, Pennsylvania, used with permission.)

Figure 9.8.
A poorly designed oval bottle may jam on a conveyor because of shingling, as shown at right.

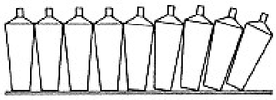

Figure 9.9.
A bottle that is wider at the top than the bottom can cause problems on the production line. The movement of the conveyor belt may cause tipping, as shown at right.

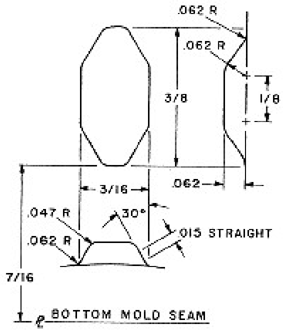

Figure 9.10.
For placing labels in register, or to avoid mold seams when decorating, a locating bar in the form of a small raised button is molded in the side near the bottom of a cylindrical glass container. This is used to orient the bottle or jar automatically on the production line.

It should be remembered that as the mass of the bottle increases, the energy of impact increases in direct proportion. What is even more significant with the continuing trend toward higher filling speeds, is that impact energy increases as the square of the velocity. That is, at three times the speed there is nine times the shock.

The shape of the body should be considered in terms of filling and labeling equipment. An oval bottle may shingle if the radius at the sides is too sharp (see Figure 9.8). If the width or thickness at the top is greater than at the base, bottles may topple when pushed together by the conveyor (see Figure 9.9). Because accurate orientation for labeling may be a problem with certain shapes, it is often wise to put an indexing dimple or button near the bottom of the main panel so it can be sensed by the machine and mechanically aligned to the proper position (see Figure 9.10).

Finishes

Glass containers can be classified as "wide-mouth" or "narrow-neck" with the dividing line at 1.35 in. (35 mm) in diameter.

According to standards set by the Glass Packaging Institute, Washington, D.C., containers also are defined by finish, which is described by size, sealing method, and special features like handles or pouring, sprinkling, and other dispensing options.

Standard container finishes are designated by two numbers, e.g., 28–410. The first one is the diameter in millimeters, measured from thread finish to thread finish with the bottle sitting on its side. The second number indicates the closing system: 400 series (continuous thread); 500 series (twist-off crown); 600 series (crown); 2000 series (vacuum); and 1600 series (roll-on).

Figure 9.11 and Table 9.7 describe some common finishes. Continuous thread (series 400) are the most widely used and can be found on an array of products from foods to beverages, pharmaceuticals and household products. Beverages also use the 1600 roll-on finish and the 500 series twist-off crown. The latter has largely replaced the conventional crown (600 series), which requires an opener to remove.

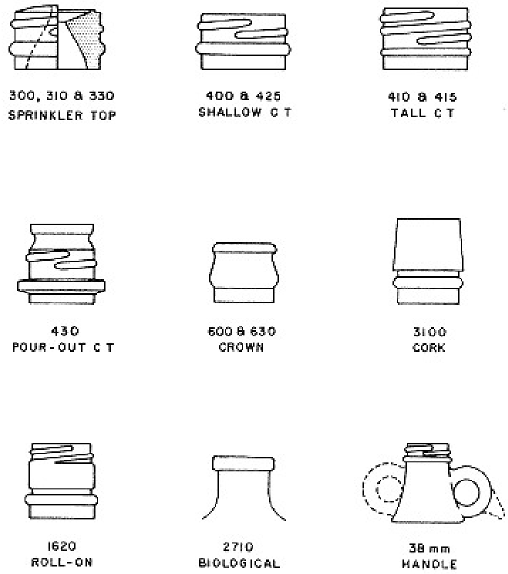

Figure 9.11.
Shown are a few of the great variety of finishes for bottles and jars. Standard finished are listed in Table 9.7

TABLE 9.7. Standard Glass Finishes.

Finish No.	Description
4	Finish Requirements for Half-Gallon and Gallon Containers with Handles (38-48)
300	Glass Sprinkler Top
310	Glass Sprinkler Top-Drain Back or Concave Style with Sealing Ring
320	Glass Sprinkler Top-Nib Opening
330	Glass Sprinkler Top-Drain Back or Concave Style
350	28 mm Linerless TE Closure Finish
360	Combination Snap Cap, CT TE Finish (Size 33)
400	Shallow CT Finish (Sizes 18-120)
400M	Metric CT Finish (Sizes 18-120)
405	Depressed Thread for CT Finishes (Sizes 8-48)
405M	Depressed Thread for Metric CT Finishes (Sizes 8-48)
410	Medium CT Concealed Bead Finish (Sizes 18-28)
410M	Metric CT Concealed Bead Finish (Sizes 18-28)
415	Tall CT Concealed Bead Finish (13-28)
415M	Metric Tall CT Concealed Bead Finish (Sizes 13-28)
420	CT Finish for PP Linerless Closure (Sizes 20-100)
421	CT Finish for PP Linerless Closure (Sizes 18-28)
422	CT Finish for PP Linerless Closure (Sizes 20-28)
423	CT Finish for PP Linerless Closure (Size 28)
424	Glass Finish for PP Linerless Closure (Sizes 36, 38, and 43)
425	Shallow CT Finish (Sizes 8-15)
430	Combination CT and Pour-out Finish (Sizes 18-38)
435	CT and Pour-out Finish (Sizes 18-38)
445	Deep “S” CT Finish (Sizes 45-83)
450	Deep CT Finish (Sizes 70-132)
455	Combination Snap and Screw Cap Finish (Buttress Thread) (Sizes 28-38)
460	Home Canning Jar Finishes (Sizes 70-86)
465	Press-on CT Finish (Size 40)
470	Deep Concealed Bead or Beadless Thread Finish (Sizes 70-86)
480	Pour-out Glass Finish (Sizes 24-38)
485	Combination CT, PE Sifter Top Snap Cap Glass Finish (Sizes 28-63)
490	Combination Snap and Screw Cap Finish (Sizes 18-63)
490M	Metric Combination Snap and Screw Cap Finish (Sizes 18-63)
495	Combination Snap and Screw Cap Finish (Buttress Thread) (Sizes 28-38)
495M	Metric Combination Snap and Screw Cap Finish (Buttress Thread) (Sizes 28-38)

Source: Glass Packaging Institute, Washington, D.C.

TABLE 9.7. (continued).

Finish No.	Description
500	Threaded Crown Finish (Size 26)
530	Threaded Crown Finish (Size 26)
530M	Metric Threaded Crown Finish (Size 26)
535	Threaded Crown Finish (Size 26)
540	Threaded Crown Finish (Size 26)
545	Threaded Crown Finish (Size 26)
550	Threaded Crown Finish (Size 26)
555	Threaded Crown Finish (Size 26)
565	Threaded Crown Finish (Size 26)
600	Crown Finish (Size 26)
611	Crown Finish (Size 26)
615	Crown Finish-Optional Sealing Surface Construction (Size 26)
630	Crown Finish (Size 26)
640	Crown Finish (Size 26)
650	Crown Finish (Size 26)
655	Crown Finish (Vending Machine Use) (Size 26)
665	Crown Finish (Size 26)
665M	Metric Crown Finish (Size 26)
710	42 mm Glass Finish Compatible with Rip Cap Closure
900	Repeal Bead Finish (Sizes 28, 28A and 28B)
910	Bail Eyelet Glass Finish (Sizes 70-450)
915	Special Glass Thread Contours
920	Glass Finish for CR Closure
1605	18 mm Roll-on Finish, 10 Threads Per Inch
1610	30 mm Short Flange Roll-on Finish
1615	30 mm Long Flange Roll-on Finish
1620	Roll-on Finish (Sizes 22-38)
1630	28 mm Roll-on Finish, 8 Threads Per Inch
1650	Top and Side Seal Finish (Sizes 28-38)
1655	Top and Side Seal Finish for Nonrefillable Services for Use with Metal and Plastic Closures, 8 Threads Per Inch
1660	30 mm Top and Side Seal, Roll-on Champagne Finish
1710	Vacuum Side Seal Pry-off Finish (Sizes 43-63)
1885	Goldy Glass Finish (Size 18)
2000	Top Seal Vacuum Lug Finish, Regular (Sizes 27 and 38)
2010	Top Seal Vacuum Lug Finish (Sizes 43 and 48)
2010M	Metric Top Seal Vacuum Lug Finish, 4 Leads (Sizes 43-48)
2020	Top Seal Vacuum Lug Finish (Sizes 53 and 58)
2020M	Metric Top Seal Vacuum Lug Finish (Sizes 53 and 58)
2030	Top Seal Vacuum Lug Finish, 4 Leads (Sizes 63-77)
2030M	Metric Top Seal Vacuum Lug Finish, 6 Leads (Sizes 63-77)
2040	Top Seal Vacuum Lug Finish, 6 Leads (Sizes 77 and 82)
2050	Top Seal Vacuum Lug Finish, 6 Leads (Size 89)

(continued)

TABLE 9.7. (continued).

Finish No.	Description
2055	Top Seal Vacuum Lug Finish, 6 Leads (Size 100)
2060	Top Seal Vacuum Lug Finish, Deep (Sizes 27-38)
2070	Top Seal Vacuum Lug Finish, 8 Leads (Size 110)
2080	Top Seal Vacuum Lug Finish, Medium (Sizes 30 and 33)
2090	Top Seal Vacuum Lug Finish, Medium (Size 38)
2200	51 mm Press-on/Twist-off Finish
2210	48 mm Press-on/Twist-off Finish
2215	48 mm and 51 mm Press-on/Twist-off Finish, 4 Leads
2710	Biological Finish (Sizes 11-33)
2720	Aerosol or Pump Glass Finish (Size 13, 15, 18 and 20)
2900	Neck Controls for Jigger Closure (Size 24 and 28)
3100	Cork Glass Finish (Sizes 28A and 34)
3105	Short Cork Glass Finish (Sizes 28A-34)
3110	Sauterne or Cognac Glass Finish (Sizes 28-32)
3115	Wine Capsule Finish (Size 30A)
3120	Square Ring Cork Glass Finish (Sizes 28-34)
3140	Natural Cork Champagne Glass Finish (Size 32)
3150	Combination Natural Cork and Crown Champagne Finish (Sizes 26-32C)
3150M	Metric Combination Natural Cork and Crown Champagne Finish (Sizes 26-32C)
3160	Plastic Stopper Champagne Finish (Sizes 26-32)
3160M	Metric Plastic Stopper Champagne Finish (Sizes 26-32)
3750	Bead Finish for Jars Without Shoulders (Sizes 54-77)

For foods and some juice products, the 2000 series is chosen because it can hold a vacuum. Since lugs hold this closure on the container, it often goes by that name. It is also sometimes referred to as a quarter-turn closure. It should be noted that lug closures should not be used in hand-capping operations because torque forces may not be sufficient to consistently insure a hermetic seal.

Friction covers often are used on food containers; for instance, on jelly glasses to preserve the smooth edge for after use as tumblers.

The finish area has its own terminology (see Figure 9.12) [5].

Manufacturing

To make glass, a mixture of sand, soda ash, limestone, and cullet or broken glass is fed into a furnace constructed of refractory brick and of either “end-port” or “side-port” design (indicating the way fuel is introduced). While fos-

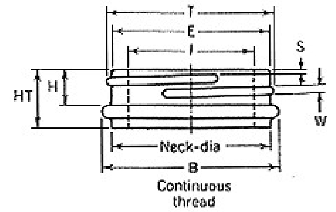

Figure 9.12.
The finish area has its own terminology. B = bead diameter; B (beta) = angle of thread helix; E = wall diameter; H = intersection of T with bead or shoulder; HT = finish height; I = inside opening through finish; S = start of thread; T = diameter of thread; W = width of thread. (Thread must make a minimum of one complete turn from center line to center line of cutter.) (Source: "Glass Container Design," Marilyn Bakker, Editor, The Wiley Encyclopedia of Packaging Technology. Copyright 1986. Reprinted by permission of John Wiley & Sons, Inc., New York.)

sil fuels are commonly used, today they usually are augmented with electric heating and some furnaces are all-electric. Generally, there is also a regenerator, which heats incoming combustion air by passing it over a stack of refractory bricks, which have been alternately heated by the exhaust gases.

The molten glass is maintained between 3.5 ft (107 cm) deep for colored glass and 6 ft (183 cm) deep for flint glass and is kept at around 2,600 F (1,427 C) by gas flames across the top surface (see Figure 9.2). The glass tank is built high above the floor and is lined with firebrick. A "throat" (narrow opening) at one end below the surface allows the glass to flow into a smaller refining chamber while it holds back impurities, which float on the surface. From there the glass flows into a feeder, where the temperature drops to about 2,000 F (1,093 C), and on into the long channel-like forehearth. The holding area can be cooled by air blown over the glass or heated by gas jets or, more lately, inserted electrodes. There also are auger-like blenders to insure homogeneity in both temperature and composition of the molten material. The latter are useful for making small batches of colored glass in less-than-furnace quantities. Coloring materials ("frits") are added right in the forehearth, which is generally longer than normal for this kind of work.

The forehearth terminates in a bowl with up to four discharge ports (depending on the number of gobs handled by the bottle machine). The stream(s) of glass are cut into gobs by steel shears. These gobs go down an iron chute for precise positioning in the blank mold(s). Here the glass is forced by a piston or compressed air into the neck ring of the mold(s), which forms the finish. At the same time, the body is given the general shape that it will ultimately have, but in reduced size, since it is not completely filled out.

This glass shape is the parison. Design of the blank mold is very important in getting good glass distribution in the final piece.

The parison is held by the neck-ring mold and carried by an arm into the final mold, where it is blown out to its finished form. It is then released from the mold, picked up at the neck by tongs, and automatically placed on the conveyor that takes it through the annealing lehr. Timing of the opening and closing of the molds and the various stages of blowing and transferring is controlled by cams mounted on a revolving drum at the back of the machine.

Coatings

To preserve the inherent strength of glass, it is necessary to avoid scratching the surface, so far as possible. One way is to coat the surface to increase lubricity and scratch resistance by minimizing abrasion from bottle-to-bottle and bottle-to-equipment contact.

Coatings typically are applied in a one-step process at the cold end (after the annealing lehr) or a two-step process, which consists of a tin oxide or titanium oxide primer coat at the hot end prior to annealing and an organic coating at the cold end. Two-step coatings provide optimum scratch protection because the hot-end coating chemically alters the surface of the glass to provide a better bond for the overcoat.

When applied correctly, hot- and cold-end coatings improve quality, durability, and appearance. Other potential benefits include:

- increased internal burst pressure (20 to 30 percent)

- potential for lightweighting and reduction of energy and materials costs and

- higher throughput and increased safety due to reduced breakage

Under actual production conditions, line breakage is reduced to a tenth or less of that with untreated containers. This is considerably more than the test results would indicate and is explained by the fact that it is the weakest bottles that break and a slight improvement affects a high percentage of the weak bottles. Therefore, improvement becomes very significant. At the line speeds of more than 2,000 per minute used for beer and baby food, breakage can be a serious problem, not only because of the loss of production, but also because of the risk of fragments contaminating the product. The importance of coatings in this kind of operation cannot be overemphasized.

Coatings are divided into nonpermanent, semipermanent, and permanent. Nonpermanent coatings such as oleic, polyvinyl alcohol (PVA), and stearate are water-soluble and best suited for slow- to intermediate-speed dry filling lines where containers are air cleaned rather than washed. PVA offers good labelability with all standard adhesives.

Semipermanent surface treatments will not completely wash off with water and include polyethylene (PE) or silicone cold-end treatment, or oleic acid over a tin hot-end coating. PE can be difficult to work with unless applied as an emulsion so it forms a discontinuous film suitable for labeling. Bonding also can be improved by oxidizing the surface of the coating with special treatments. Polyethylene glycol and the stearate of polyethylene glycol are much easier to handle than plain PE.

Permanent surface treatments such as a tin oxide or titanium oxide hotend coating overcoated with PE wax withstand water washing, pasteurization, or retort processing and offer superior dry and wet scratch resistance and lubricity. To ensure adherence and performance, label stock and adhesive should be carefully tested to ensure compatibility with the coating.

Coatings used on glassware for food or internal medication should be made from materials that are listed as safe by the Food and Drug Administration, Washington, D.C. Requirements are found in the Code of Federal Regulations (CFR) Title 21, Food and Drugs, Subpart C—Substances for Use as Components of Coatings, Part 175.300 (xxxvii)(c)(1), which permits the use of approved polymeric coatings on one-use containers not exceeding 1 gal (3.79 L) in size where the extractive level shall not exceed 0.5 mg/in.^{2} (6.5/cm^2) of food contact surface or 50 ppm of the water capacity of the container [6].

If an overflow filling system is used, as with pickles, olives, and cherries, there is a risk that the coating on the bottles may be washed off and become concentrated in the system as the material is recirculated. Silicones would not be as much of a problem as stearates, for example, because they are less soluble.

Tests to determine the effectiveness of surface treatments include slip angle and scratch resistance. When properly coated, most bottles will show a slip angle of 10 to 12 degrees and a scratch resistance of 100 lb or more [7].

To ensure coatings are applied evenly and in the proper area, routine quality control testing checks distribution and positioning. Hot-end coatings on the finish area, for example, can cause closure rusting and increase removal torque; while cold-end coatings on the finish have the opposite effect, a reduction in removal torque, increasing the chance of leakage.

Quality Control

Glass containers are rigorously inspected by automatic equipment before leaving the manufacturing plant. Electro-optics, electromechanical, and radio frequency techniques are used to check for a variety of defects and inconsistencies. Defective containers are recycled as cullet in a future batch.

In one system, electronic visual stations inspect for defects such as birdswings, blisters, stones, black marks, cloudiness, stuck glass, lehr cracks, mottled containers, blow-outs, folds, laps, slugs, swab ware, leaners, and height/diameter deviations. Height, plug gauge, and dip/saddle finish are then examined on a dual head gauger and a squeeze tester identifies cracked and weak containers. The final station, an automatic inspection machine, checks for splits in various parts of the container, thin walls, out of roundness, and birdswings.

In an effort to position quality control closer to the IS machine, there's been considerable developmental activity in recent years to move some inspection activities to the hot end to check for dimensional problems, leaners, freaks, birdswings, gross visual defects, and gross thickness variations.

On the packaging line, users of glass containers usually take a random sample of at least 100 containers and preferably 300 or more per lot to ensure that critical defects are not missed. Samples should not be taken from cases that show shipping damage (see Chapter 19, Quality Control). If critical or major defects exceed the limits, the glassware should be rechecked. If defects are still excessive, the lot should be rejected. For minor defects, which are beyond the limits, the lot is sometimes accepted with a warning to the supplier.

Defects

If the inside surface dips below the parting line, which is generally about 1/8 in. (3.18 mm) up from the bottom, it is called a "light bottom," and the container is likely to break at this point on the production line or in shipment if it is dropped on a hard surface. Another source of damage, which does not occur very often, but is peculiar to certain types of products, is a chipping of the inside surface at the center of the bottom panel. If a bottle of vacuum-packed heavy syrups or pureed foods is dropped, the vacuum in the headspace may suddenly plunge to the bottom. The resultant bubble collapses rather quickly, but in doing so concentrates sufficient hydraulic force at this point to chip the surface, which is consequently weakened.

The failure of a glass container is usually the result of thermal shock or impact stresses. It is desirable to know the cause of the damage and, by examining the fragments, it is possible to learn a great deal about the stresses that caused the break. Although it takes some training and experience to make a precise evaluation, it is useful to know some of the principles involved.

Glass fails only in tension, never by compression. Therefore we can reconstruct the container from the pieces and read a history of why it failed from the shape of the fragments. A fracture moves out from the point of impact in

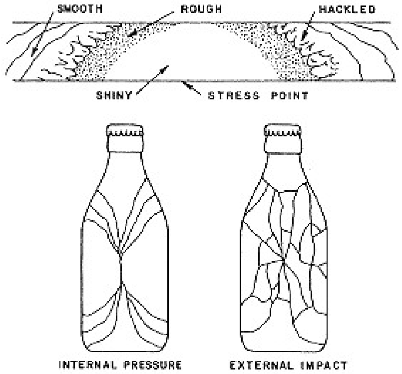

Figure 9.13.
Fragments of glass can reveal considerable information about the severity and type of stress that caused the failure of a container. A mirrorlike surface indicates a rapid fracture, usually at the starting point. A rough surface occurs where the fracture proceeded at a slower rate. The shape of the pieces will show the type of shock; thin slivers usually indicate an outward force, and short chunks indicate a blow inward.

a series of waves. The broken surface nearest the point of impact is smooth, shiny, and flat, indicating that it separated rapidly. Farther away it is angular and rough, especially near the edges, where the break occurred more slowly. Still farther away, the surface again becomes smooth and flat (see Figure 9.13)

There are six broad classifications of glass defects: (1) checks; (2) seams; (3) nonglass inclusions; (4) dirt, dope, adhering particles, or oil marks; (5) freaks and malformations; and (6) marks. These vary in importance, depending upon severity, but the type of defect usually will determine its seriousness. Defects can be grouped as:

• critical—those that are hazardous to the user and those that make the containers completely unusable because they are freaks or did not completely fill the mold

• Major—those that materially reduce the usability of the container or its contents

• Minor—those that do not affect the usability of the container, but detract from its appearance or acceptability to the customer (see Figure 9.14 and Table 9.6)

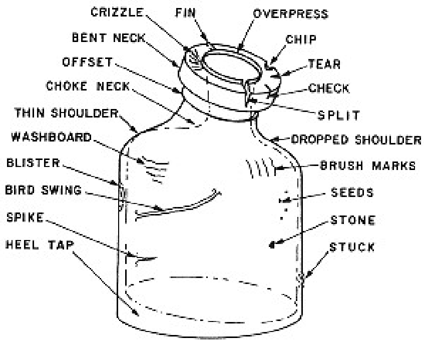

Figure 9.14.
Shown are some of the typical faults that may be found in bottles and jars. Many of these are very rare, but others will be found more frequently.

Labeling

The pristine surface of glass as it comes from the mold is very reactive and quickly combines chemically with the moisture in the air to form OH hydroxyl groups. This means that the surface is negatively charged and readily wetted with water, alcohol, and other substances with similar OH groups in their chemical formulas. Likewise, NH_3 amine groups, such as are found in dextrin or casein molecules, will readily adhere to glass. Thus the glass can be said to be hydrophilic in character, and as long as the adhesives are neutral or alkaline, a good bond will result from the chemical action with the OH molecular groups on the surface. The adhesive should be used in as thin a film as possible, to avoid residual stresses as it dries, which would weaken the bond.

Opal glass is difficult to label because the fluoride ions cause the surface to be hydrophobic. This makes it difficult to get good wetting action. Silica and quartz glass are difficult to label for the same reason. Borosilicate glass is not quite as bad, but the acidic nature of boron compounds can cause some problems.

Moisture condensing on the surface of a glass container can sometimes interfere with labeling. If bottles are brought from a cold warehouse to the filling line, which is at room temperature, dew will form on the surface. This may be a barely perceptible amount, yet it can prevent the adhesive from sticking to the surface of the glass. The solution, of course, is to allow enough time for the ware to warm up before putting it into the filling line. For more information on labeling, see Chapter 12, Labeling and Decorating.

Decorating

Surface coloration called luster decorating can be applied to glassware using organic compounds of tin, bismuth, iron, titanium, and other metals dissolved in hydrocarbons or chlorinated hydrocarbons. The pieces are then fired at 1,000 F (538 C) in an oxidizing atmosphere to provide a metal oxide film. Two different coats with a firing in between produce attractive results, especially if the base coat is gold or platinum. Treating the second coat with ethyl acetate, while it is still wet, produces a marbled effect.

The luster can be applied by spraying, dipping, silkscreen printing, and several other techniques. Some luster coatings closely resemble colored glass, and are used for short runs if coloring the glass in the tank would not be practical. They have resistance to abrasion and to detergents. Available colors are pink, copper, orange, turquoise, and light and dark blue. These colors cannot be mixed to produce other colors because the results do not follow the usual rules and the effect is usually disappointing.

Colored coatings of the epoxy type provide a certain amount of surface lubricity and thus reduce breakage on the production line and in transit. They also provide the decorative effect of the color and protect the product from light.

Another heat-treatment technique, applied color lettering, can be used to apply permanent graphics and copy in multiple colors. After designs are silkscreened in place, containers are fired in a decorating lehr to fuse the organic ink onto the container. A similar process, capable of clearly reproducing 4-point type, eliminates heavy metals from the ink with a 100 percent solids polymeric formulation that bonds to the glass and is cured with ultraviolet light.

Tubing Products

Glass tubing is made by drawing molten glass through a die mounted on the furnace in a horizontal direction until it is cool enough to be cut to length. The soft tubing is supported on rollers as it leaves the die, and every few feet there are more rollers to keep it from sagging. After it has traveled 100 ft (30 m) or more, automatic equipment nicks and snaps off lengths of approximately 10 ft (3 m) for sorting by a machine that gauges the outside diameter at several points and rolls it into one bin or another, according to its diameter.

From this tubing can be made a variety of containers, such as vials, small bottles, and ampuls, as well as applicator rods, pipettes, and syringe barrels. Type I glass frequently is used because it is more resistant to chemical ac-

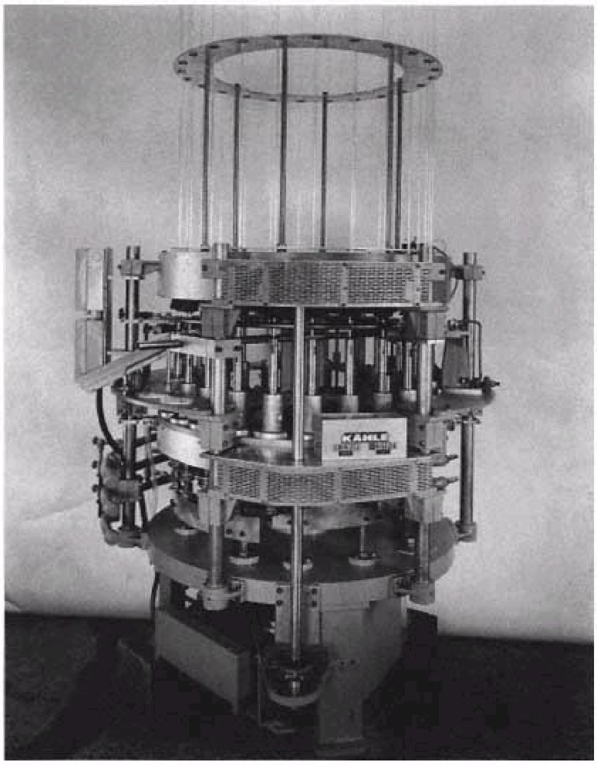

Figure 9.15.
To create vials, ampules, and bottles, 10-foot lengths of glass tubing placed in the turret feed down as the tubing machine rotates. Gas flames heat the glass, and forming tools cut and shape the piece into a finished container.
(Source: Kahle Engineering Corp., Orange, New Jersey, used with permission.)

tion. It also tends to be more uniform and, therefore, can be more consistently worked by the machines that make these articles (see Figure 9.15). However, Type II and III glass also are available and lower in cost.

Small bottles of 30 cc (1 fl oz) capacity or less can be made from tubing and will have certain advantages over the usual molded bottles. A more uniform thickness means walls can be made thinner. In the small sizes, a change from molded to tubing containers can result in as much as a one-third reduction in weight. Thinner walls offer better clarity and there's a complete absence of black specks and other defects resulting from mold dope. Since there are no mold seams, decoration is easier, too. Finally, delivery tends to be quicker—12 to 16 weeks—compared to 16 to 20 weeks for blown ware.

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Chapter 10— Metal Containers

History

The quest for a container that would better protect the quality of foods and led to the development of the tin can was started by Napoleon's offer of 12,000 francs for a method of preserving food to sustain his army. This award was claimed by a Parisian chef and confectioner, Nicolas Appert, in 1809 for his new process of canning. Ironically, this innovation was developed fully two generations before the microbiological causes of spoilage in foods were discovered by Louis Pasteur.

A year later Peter Durand, an Englishman, invented the "tin canister," and when William Underwood migrated from England to Boston in 1817, he brought the beginnings of the U.S. canning industry with him, although he used glass jars [1]. The first U.S. appearance of preserved food in cans is credited to Thomas Kennsett, another British transplant, and his father-in-law Ezra Daggett, who formed a partnership in New York in 1819 [2].

For a long time, cans were made slowly and laboriously by hand out of tinplate. Both ends were soldered to the body, with a hole about 1 in. (25 mm) in diameter in the top. After the can was filled through this hole, a metal disk was soldered into place. The disk also had a tiny hole in it, which was soldered after the "cooking" process was completed.

Mechanization of the can-making process was made possible by the development of a crimping method to attach ends to the soldered can body. Called double seaming, it was patented in 1896 by a New Yorker named Max Ams [3].

A modern alternative to soldered side seams is cementing, which is used for some dry products. Even more recent is the welded side seam, which eliminates both solder and cement, further speeding manufacturing and creating a stronger can, particularly for aerosol products.

A newer production method creates a two-piece can by eliminating the side seam and one end seam. This is achieved by stamping a cup-like shape from aluminum or steel and then "drawing and ironing" (D&I) the thick-walled cup into a can. It made the advent of an aluminum can possible since this metal cannot be soldered and is difficult to weld. Introduced in 1965, this two-piece style has had great impact for products where the can size is uniform. In the beverage business, for example, two-piece cans have completely displaced three-piece (see Table 10.1) [4].

D&I containers offer the lowest unit cost and have continually improved by successive stages of "necking-in" operations that reduce the diameter of the can top, thus allowing the use of smaller, less expensive ends. Quintuple "steps" are now possible and a spin-necking operation can smoothly taper the necked-in area.

An alternate two-piece method is a draw-and-redraw (DRD) technique. Its practical basis is pressurized beverage cans, but it also is capturing food markets because its structural simplicity affords greater product protection. As a result, shallow- and deep-drawn aluminum food cans produced by the DRD process are gaining market share.

A third two-piece production technique is the draw-thin-redraw (DTR) process. It is targeted as a lower-volume, less capital-intensive alternative to D&I steel cans.

The above constructions have made it possible to develop high-speed equipment for making, filling, and closing cans. The original handmade cans were produced at the rate of ten per day [5], but modern machines manu-

TABLE 10.1. 1995 Metal Can Shipments by Material, Technology (in millions).

	Material		Material Can-Making Technology	
Market	Steel	Aluminum	2-Piece	3-Piece
Beverage	1	98,115	98,116	0
Food	28,157	3,156	13,528	17,785
Aerosol	2,879	14	20	2,879
Paint/Varnish	827	0	0	827
Automotive	94	0	0	94
Other Nonfoods	461	14	20	455
TOTAL	32,419	101,285	111,664	22,040

Source: Can Manufacturers Institute, Washington, D.C., used with permission.

TABLE 10.2. 1995 Markets for Metal Cans.

Market	Units (billion)	Market Share (%)
Soft Drink	62.6	47
Beer	35.5	27
Food	31.3	23
General Packaging	4.3	3
TOTAL	133.7	100

Source: Can Manufacturers Institute, Washington, D.C., used with permission.

facture small ends at speeds to 2,500 per min. A few beverage packagers have managed to fill such cans at speeds of 2,000 per min, although the lines are generally run slower than that to improve efficiency.

In 1995, U.S. can shipments totaled nearly 134 billion and were valued at more than $12.1 billion. Looking at it another way, Americans open about 200 million cans every day [6]. These are divided among a wide range of products (see Table 10.2).

Advantages and Disadvantages

Metal cans are produced from readily available, highly recyclable materials and offer impermeability to moisture, gases, and light, as well as potential for high-speed manufacturing and filling. Many designs today offer easy-opening ends that do not require the use of a tool to access the contents.

For aluminum, use of recycled cans to produce new ones results in no loss of properties and reduces energy requirements 95 percent compared to virgin sources because extracting aluminum from bauxite is extremely energy intensive.

Aluminum also offers light weight, good thermal conductivity, resistance to oxidation, solvents, and greases, and an attractive reflective surface. On the down side, the material must be coated to protect it from most acids and alkalis as well as scuffing and abrasion.

Steel is compatible with many products, offers stacking strength, thermal stability, and a good surface for decoration and coating. Its magnetic quality simplifies recycling and also can be used to aid material handling. Negative aspects include the material's relatively heavy weight and susceptibility to corrosion. In addition, some steel can stock must be treated before welding.

As far as can types are concerned, two-piece designs are viewed as having an advantage over three-piece because there is less chance of leakers when there are no side and bottom seams.

On the minus side, the cost of setting up a production line for two-piece cans, especially a D&I line which represents an investment of about $30 million, is vastly greater than that for three-piece. Food processors also need a variety of sizes for different products harvested in different seasons, and the D&I can has not lent itself as readily to this diversity.

Some two-piece DRD steel cans are being made for the food industry in sizes up to 401   411 (page 338 defines can dimensions), but the problems of maintaining the same dimensions as three-piece cans (for interchangeability in process equipment) has been a stumbling block. DRD lines also appeal to the food industry because they cost about two-thirds less than a D&I production line.

Can Materials

Cans made from black plate, chromed plate, laminated steel, and aluminum have joined the original tinplate material.

Steel

Although commonly called "tin" cans, this is a misnomer. If these containers have any tin at all, it is only as a very thin coating on one or both sides.

The standard of measurement for steel, the base box, is equal to 112 14   20 in. (35.6   50.8 cm) sheets or 31,360 $in.^2$ (20.2 m^2) of total surface on one side of the plates and 62,720 $in.^2$ (40.5 m^2) of total plate surface on both sides. Weights usually fall between 45 and 135 lb/base box (20.4 to 61.2 kg). This is equivalent to a thickness of 0.0050 to 0.0149 in. (128 to 382 m) [7].

Various steel alloys are used to make cans. The main ones for tinplate are MR, L, N, and D. The most commonly chosen, MR, is relatively low in residual elements and suitable for vegetable and meat products. Even lower in residuals is Type L. It is intended for packing corrosive food products. Residual elements such as phosphorus, sulfur, silicon, copper, carbon, and manganese are limited to the least practicable amounts. Nitrogen imparts strength to Type N, which is used for ends and aerosol domes. Type D, a nonaging steel with a minimum of carbon, contains some aluminum to improve drawing. It is used for deep-drawn parts where freedom from fluting or stretcher strains is required.

Most low-carbon steel for containers, today, is refined in a basic oxygen process and either cast into ingots or, more commonly, continuously cast into slabs that are rolled in a hot-reduction process to a thickness of 0.075 to 0.100 in. (1.91 to 2.54 mm), which is the starting point for what are called "tin-mill products." From this point, a considerable number of steps are required to achieve the final can material.

First, the "hot-band" or steel slab is pickled in sulfuric or hydrochloric acid to remove scale and coated with oil to prevent rusting and lubricate the sheet for cold rolling. This is done in a mill equipped with five or six rolls that reduce the thickness of the steel strip up to 90 percent at very high linear speeds to its final gauge for a "single-reduced" product. Double-reduced steels are not rolled quite as heavily in this operation.

The "full hard" product is very brittle, however, and must be scrubbed to remove the surface oil and annealed to create a ductile can material. Either batch or continuous annealing is practiced, with the latter more usual. Batch annealing of the steel coils in an oven surrounded by an inert gas at temperatures up to 1,300 F (704 C) is a slow process that enables steels of softer temper to be produced. Continuous annealing in an inert-gas environment is faster and more uniform than the batch process, but makes it difficult to attain soft products. After annealing, double-cold-reduced (2CR) plate goes through a second mill to thin the gauge another 35 percent. Its greater stiffness permits can makers to use lighter gauge weights and cut costs.

In the next step, both single- and double-reduced steels are subjected to "tempering," another light cold-reduction of about 0.5 to 2 percent. It gives the metal some spring and determines the final surface finish by the use of shot-blasting and/or grinding to create either a rough or smooth surface.

Numerous tempers are available and are graded according to their hardness (see Table 10.3). Generally, the steel used for ends is a stiffer temper than that used for the body. The other rule of thumb is that can makers choose the highest workable temper in order to produce the strongest can at the lowest cost.

Steel that has completed the tempering process is termed "black plate" (because in early production days it was covered with a black oxide at this point). Traditionally, it is used for spice containers and a number of industrial-packaging applications. It also is the basis of tinplate and electrolytic chromium-coated steel (ECCS).

Tinplating originally was conducted by passing the steel strip through a bath of molten tin. This hot-dipping process has been replaced by electroplating. Developed during World War II when supplies of quality tin from Malaysia were cut off, electroplating produces a more uniform coating with less material. In this process, the coiled black plate is unreeled through a caustic scrubbing and a light pickling to clean the surface. Plating is done with either an acid stannous sulfate or halogen process and produces a matte finish. It can be retained, as it is for crown closures, or brightened by "reflowing" the tin coating at a temperature just above its melting point and then water-quenching it to set the resultant shiny surface. A satin finish can be produced by applying the tin coating before the final cold reduction. An

TABLE 10.3. Tempers of Tinplate.

Temper	Rockwell Hardness 30-T Scale	Applications
T50	46–52	Nozzles, spouts and closures; deep drawn parts
T52	50–56	Shallow-drawn and specialized can parts
T57	54–63	Can ends and bodies, large-diameter closures and crown caps
T65	62–68	Stiff can ends and bodies for noncorrosive products
T70	67–73	Very stiff applications
DR8	70–76	Round can bodies and ends
DR9	73–79	Round can bodies and ends
DR9M	74–80	Beer and carbonated beverage can ends

Rephosphorized to resist buckling.

Double-reduced.

electrochemical passivation treatment, usually with sodium dichromate, stabilizes the surface and adds a thin film of metallic chrome, chrome-oxide, and tin oxide. Oil is then applied to enhance corrosion protection and protect the tin layer during container forming (see Figure 10.1).

Although the tin coating is only about 0.000012 in. (0.30 m) thick, conventional tinplate resists corrosion not only by the protective layer of tin on its surface, but also by a cathodic reaction that minimizes oxidation at any pinholes or bare spots that may be present. A tin coating also prevents the iron from being dissolved in certain beverages and food products, which would acquire an undesirable iron taste.

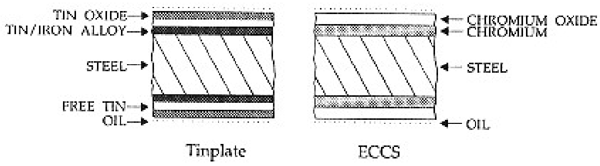

Figure 10.1.
Most cans are made of tinplate (left) or ECCS. The tin or chromium coatings provide corrosion resistance but may require an additional enamel layer for product compatibility.
(Source: Gordon L. Robertson, ed. Food Packing: Principles and Practice. 1993; p. 180. Reprinted with permission, Marcel Dekker, Inc., New York.)

Tin coating thickness is designated according to its weight on one base box. For example, #25 plate has 0.25 lb (113.4 g) of tin per base box (436 ft^2, 40.5 m^2) or 0.125 lb (56.7 g) on one side of the sheets [8].

Before World War II, tin coatings generally ranged from 1.0 to 1.5 lb/base box (453.6 to 640.4 g). Coatings now range from 0.1 to 1.0 lb/base box (45.4 to 453.6 g). The steel also can be differentially coated with less tin on one side than the other, depending on whether the product or the environment is more severe. An example of differential coating is 0.250 lb (113.4 g) on one side and 0.125 lb (56.7 g) on the other, a total of 0.38 lb/base box (172.4 g/base box). A light pattern is embossed on the tinplate to indicate the amount of coating and the side with the heavier deposit (Figure 10.2).

However, the protective value of the tin without any additional coatings is somewhat limited. When the can is exposed to atmospheric conditions of high humidity, rust will develop rapidly. On the inside of a sealed can, oddly

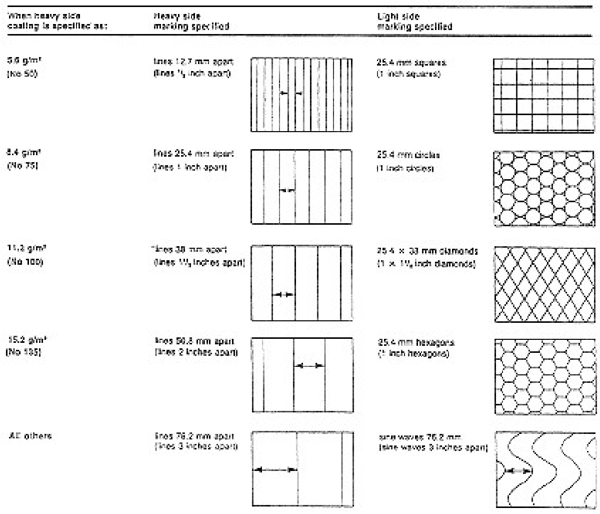

Figure 10.2.
Differential coatings reduce the amount of tin required and puts a heavier deposit on the side where it is needed the most. An embossed pattern indicates plating weight and the side with the heavier coating. (Source: Institute of Packaging Professionals, Fundamentals of Protective Packaging Course, 1990, used with permission)

enough, the polarity of the two materials changes and there is considerable protection against corrosion and pinholing by electrochemical action of the tin with the steel. Nevertheless, a number of inside linings and outside lacquers have been developed over the years to protect the metals from attack by product constituents and environmental forces, respectively (see Can Linings, page 337).

The expense and sometimes difficult sourcing of tin fostered interest in tin-free alternatives. The result was ECCS. It offers greater heat resistance, superior coating adhesion, lithographs well, and resists stain formation from sulfur-containing foods [9]. Because of its lower cost and functional attributes, ECCS now dominates the end market and is widely used for bodies as well, especially for DRD food cans.

ECCS is a chromium/chromium-oxide-coated steel initially developed in Japan and improved in the United States. Using a one- or two-step process, an extremely thin layer of metallic chromium 0.3 10^{-6} in. (0.008 m) is electrolytically deposited on black plate and then oxidized.

To be effective, additional coatings must be applied to both sides of ECCS because it does not offer the corrosion and galvanic protection the tin coating imparts to tinplate. For three-piece cans, ECCS is not compatible with soldering, but may be cemented. Side seams also may be welded if the chromium layer is removed from the edge.

Another can-making material using steel is a metal/polyester laminate that eliminates the need for a lining. Printed polyester/metal/polyester under development in Japan would eliminate both decorating and coating steps [10].

Aluminum

Packaging uses of aluminum can be separated into two categories: flexible and rigid. Metal foils for bags and pouches are discussed in Chapter 3, Films and Foils.

The composition of aluminum alloys for rigid containers varies according to the intended use, with up to 5 percent magnesium, 1.5 percent manganese, and traces of iron, silicon, zinc, chromium, copper, and titanium. As forming characteristics and resistance to corrosion improve, yield strength usually goes down and heavier gauges are required to do the same job.

Cold working causes aluminum to strain-harden, and a 50 percent reduction in size by rolling results in about 30 percent higher yield strength. This will drop off with time, declining perhaps 5 percent per year due to an age-softening phenomenon. When enamels or other coatings are baked on, there is also a slight drop in yield strength.

The extra stiffness of work-hardened material is used to advantage in making container bodies and ends. The sheet rolling process also results in what is called "preferred orientation," which shows up in the form of ears around the rim of a formed piece, usually 90 apart. This can be controlled to some degree by changing direction during rolling and annealing between passes.

It took the development of a special 3004 aluminum sheet, containing manganese and magnesium, later changed to a harder-tempered 3004-H19 alloy to achieve the very thin gauges that make aluminum container bodies economic. Internal pressures in carbonated beverages and beer help strengthen the containers as does the development of special recessed and beaded can bottoms, which tolerate the heat-processing pressures of beer pasteurizing and provide the minimum column strength brewers require, 300 lbf (1330 N) [11].

The success of the two-piece can is partly due to the development of the ring-pull opening device on a can end made from 5182 aluminum alloy with a higher magnesium content. Aluminum ends also are used to provide easy opening for some tinplate cans, a structure that's termed "bimetallic."

For deep-drawn containers and impact-extruded cans or tubes (see page 343, 352), an alloy with good workability is necessary. The annealed forms of alloys 1050 and 1100 are among the best for this purpose due to their purity.

Shallow-drawn parts, such as can ends, use alloys with less ductility and medium temper so that the flat panel that does not get worked will have sufficient stiffness. Alloy 5052 is one of the most popular for this, and a temper of H34 is about right for average conditions. For can bodies, a harder temper, H19, is more suitable in thicknesses of 0.008 to 0.020 in. (205 to 512 m).

Can Linings

Metals used in can making often do not provide sufficient corrosion resistance, product/container compatibility, and surface abrasion resistance. As a result, a variety of lacquers and lining materials can makers call enamels have been developed to protect outer and inner surfaces, respectively. Application is by roller or spray to flat sheet or coil followed by an oven or ultraviolet (UV)-light curing process. For two-piece cans, linings are sprayed on or applied by electrophoretic deposition, which improves coating utilization and coverage [12].

Corrosion of the inside of the container is usually one of two general types. The first, a surface corrosion, proceeds gradually but does not penetrate very deeply. It is fairly easy to control by following good practices in storage and processing operations such as proper cooling and drying of retorted cans and protection from corrosive vapors and condensation during warehousing and shipping.

The second type of corrosion is pitting or perforating, in which the effect is localized and often difficult to see. It may not affect the product but can cause leakers. Although it most often occurs at the surface line of the product, it can occur above in the vapor-phase area (headspace) or below in the liquid phase, depending upon the nature of the contents.

Certain product or packaging components can aggravate corrosion, and characteristics like acidity, pH, and oxygen levels also have an influence. Even cannery water can have a negative effect if levels of certain constituents are too high. Corrosion accellerants include copper, even in small amounts, such as might be picked up from certain fungicides, pipes, or mixing vessels; sulfur compounds from agricultural chemical residues or preservatives; nitrates from fertilizers; phosphates; anthocyanins and related plant pigments; and synthetic colorants such as azo dyes.

The enamels protect the surface of the can by serving as a barrier to gases, liquids, and ions [13]. Enamels such as oleoresin, alkyd, vinyl, vinyl organosol, acrylic, phenolic, epoxy-amine, polybutadiene, and epoxyphenolic generally are formulated to suit a particular product. For example, an oleoresin coating known as berry and fruit enamel prevents these products from being discolored by tin salts. Oleoresins pigmented with zinc oxide are dubbed C-enamels and used for vegetables (like corn) and meats to counteract the dark sulfide compounds that form in these products in the presence of tin. Phenolics have replaced oleoresins in some cases and because of limited flexibility are best suited for three-piece cans [14]. Vinyls are more flexible but somewhat sensitive to heat. Epoxy-phenolics combine good adhesion properties with high chemical resistance and vinyl organosols offer flexibility compatible with DRD forming. Enamels generally are specified in terms of mg/in.^{2} (mg/6.5 cm^2).

For aluminum beverage cans, there has been a shift to coil coating with vinyl, epoxies, and modified epoxies, as well as growing interest in water-based systems to reduce volatile organic compounds (VOCs) [15]. Bevcan ends are treated with various materials. PVC is commonly used, although water-based PVC-free formulations also are available.

Can Manufacturing

In the United States, can dimensions generally are specified by three-digit numbers, i.e., 307 113. The first digit stands for the number of in., while the other two represent sixteenths of an in. So, the 307 113 would be 3-7/16 1-13/16 in. However, standards established by the International Standards Organisation, Geneva, Switzerland, specify that the body plug diameter and height be rounded to the nearest whole mm and the Can Manufacturers Institute, Washington, D.C., recommends U.S. suppliers make the transition. So, the 307   113 can would be described as 87   46 mm [16].

The fastest body- and end-making machines can operate at speeds to 2,500 per min. Cans are commonly shipped to the packer in paper bags, or "carriers." Ends are rolled into paper tubes. Another alternative is reshipper delivery where the corrugated cases in which the cans are delivered are reused to ship filled product. Large users receive cans in bulk pallet loads which consist of layers of cans separated only by chipboard and entirely overwrapped with paper or film. Bulk railcars, connected to canning lines by can-track conveyors, are employed by truly big users.

Automatic equipment is available for depalletizing cans in a packer's plant. This equipment is feasible because even though special cans are created all the time, the majority of big-volume cans are standardized (see Table 10.4).

Three-Piece Cans

Three-piece cans usually are delivered to the packer with one end in place and the other shipped separately. After filling, the second end is double-seamed by closing machines, which can change the headspace air to a vacuum or inert gas, if required.

To make three-piece cans, finished steel sheets measuring 1 to 2 ft wide and 2 to 3 ft long (30.5 to 61 cm and 61 to 91 cm) are cut into can-width strips on a machine called a slitter. The slit strips are cut into body blanks and fed into a body maker, the first machine in an automatic can line. In the body maker, the corners are notched to remove the extra thicknesses of metal where the side seam is curled into the ends (see Figure 10.3).

TABLE 10.4. Dimensional Food Can Standards and Costs for Selected Three-Piece Sizes.

Name	Dimensions	Capacity	Cost/M
6Z	202 308	6.08	$15.25
No.I (Picnic)	211 400	10.94	$26.57
No.211 Cylinder	211 414	13.56	$26.86
No.300	300 407	15.22	$27.66
No.303	303 406	16.88	$28.58
No.2	307 409	20.55	$36.31
No.2.5	401 411	29.79	$45.11
No.3 Cylinder	404 700	51.70	$81.44

Avoir, oz of water at 68 F.

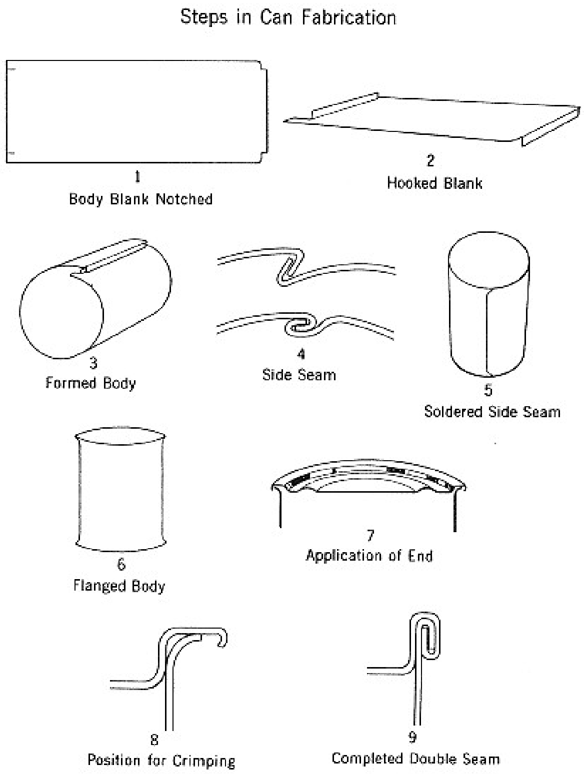

Figure 10.3.
The body blank is notched to eliminate some of the extra thicknesses of metal where they overlap. The edges are hooked and bumped together, and then soldered, cemented, or welded. The end pieces are placed over the flared ends of the body, and the edges rolled together by a crimping machine.
(Source: American National Can Co., Chicago, used with permission.)

The next machine, the side seamer, solders, cements, or welds the joint. When soldered, it is necessary to avoid decoration in the area near the joint, so that bare metal will be exposed to accept the solder. Once soldered, the joint may be "striped" inside and possibly outside to restore the coating.

At one time, solder might consist of lead, tin, silver, or antimony in various proportions. However, due to its toxicity, the National Food Processors Association, Washington, D.C., began phasing out lead-soldered food cans in 1979, a process that was completed in 1991. Since then, the Food and Drug Administration (FDA), Washington, D.C., has issued a final rule that prohibits the sale of any food in lead-soldered cans. This includes imported products.

Today, solder used in can making consists of tin and silver, a soft material with a relatively low melting point (450 F, 232 C) [17]. The tin aids bonding and the silver increases resistance to "creep," or plastic flow, the very slow movement of the solder when the can is under constant stress, as in the case of some aerosols. Creep may eventually break the solder bond, resulting in failure, even though the original breaking strength was probably above 400 psi (2.8 MPa) of internal pressure. Tests on solders should extend over a 2-year period to determine resistance to creep and the effects of the product on the solder.

For some dry and nonfood products, the side seam can be cemented instead of soldered. Cemented side seams permit all-around lithography with no bare strip required at the solder joint. The body former curves the sheet to form a cylinder and overlaps the edges. A polyamide- or organosol-based adhesive forms the seal on the heated overlap, which is then quickly chilled while being held under compression. The nylon adhesive used is strongest when in shear rather than in tension, so a lap seam is better for this purpose than a hooked seam. The outside appearance of the cemented cans is excellent with no bare metal exposed. Cemented side seams using nylon adhesives may be heat processable. A thorough test program should be followed, however, before cemented side seams are used for cans under pressure.

Welded side seams are very strong and require a much narrower undecorated strip than that needed for soldering. In welding, the side seam is an overlap of the curled plate, which is subjected to a high-amperage electric current in a resistance-welding process. The resulting exposed iron edge inside the can is coated in a striping operation sometimes using newer powder coatings, which are cured by infrared or high-frequency induction heating. Welded side seams for containers made from ECCS are suitable for most purposes and provide a neat appearance on the outside with a narrow strip of less than 0.28 in. (7 mm) of exposed bare metal.

Seamed bodies transfer to a flanger, which flares top and bottom edges to receive can ends. Cans destined for heat-processed foods frequently are ribbed, a process known as beading, to strengthen the body against collapse both from external processing temperatures and the internal vacuum that develops as the product cools. Since beading increases the amount of sheet in the body, reduces top compression strength, and creates problems with labeling, much work has been devoted to developing patterns that increase hoop strength while minimizing the negatives.

Plate for can ends, typically precoated and printed, if desired, is sheared into scrolled strips for the most economical layout. If cut in a straight line, there would be triangular sections of waste material along the edges between the circular ends. In order to reduce this waste, the edge is sheared in a wavy line, and the amount that is saved becomes a part of the adjoining strip. The scrolled strips are transferred to a punch press, where the ends are blanked out and the edge is curled. The ends for sanitary cans of all kinds have concentric beads, which flex to accommodate the heat-processing pressures and internal vacuum. A flexible sealing compound is then flowed into the curl and allowed to dry. The compound, typically made from pure latex, synthetic rubber, or a soft plastic material, is applied from a nozzle while the can end revolves in a holding chuck. Two complete turns are made to ensure even distribution. The curled ends and flared bodies are joined in a machine called a double-seamer (see Figure 10.4) and sent to a leak tester.

Double seaming, which curls and folds body and end edges together to produce an airtight seal, also has been improved with a microseaming technique developed in Brazil that halves the size of the seam and reduces metal requirements up to 15 percent [18]. FDA has issued a letter of no-objection for use of microseamed cans with low-acid and acidified food products, but it's not widely used yet in the United States.

Two-piece Cans

D&I, or what sometimes are termed "drawn and wall-ironed" (abbreviated DWI), cans are used almost exclusively for beverages, since the thin walls could not withstand the pressure and vacuum created during the pro-

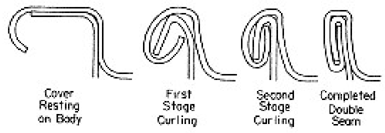

Figure 10.4.
The stages required to attach an end to the body in a double-seaming operation are shown enlarged. Sealing compound between the two pieces was omitted for clarity but plays a vital role, serving as a gasket and enabling formation of an airtight seal.

cessing of food products. To make a D&I can, a disk of aluminum (or tinplate) is formed into a shallow cup with a male and female die. The cup is then pushed through several other dies, each slightly smaller than the previous one, so that the side walls are stretched and thinned (see Figure 10.5). Since the cup is held on the original punch, or one just like it, the inside dimension remains constant during this process. Starting with a plate thickness of 0.0114 in. (292 μm), the side walls are reduced to 0.0038 in. (97 μm) while the bottom remains 0.0114 in. (292 μm). As the walls are ironed, the bottom is domed to provide strength and stability. Can bodies are then trimmed to length and, if required, cleaned in preparation for coating inside and out, beaded and/or necked-in. The final step flanges the open end.

The DRD method differs in that the inside dimension of the cup becomes smaller as it is pushed through each succeeding die and the gauge of the bottom and side wall of the finished container remains essentially the same as the starting gauge. DRD cans are made of ECCS and used for food applications due to the material's better enamel adherence and heavier walls. A typical can for vegetables would start with 65-lb (29.5-kg) steel having a 0.0072-in. (184.6-μm) gauge and end up with a side wall of 0.0070 in. (179.5 μm). The maximum ratio of height to diameter is about 1.5:1, while for a D&I can, it is 2:1.

The DTR method draws and stretches precoated double-reduced steel to optimize wall geometry, resulting in reduced gram weights and lower material costs. This is done by retaining the flange throughout the drawing process to maintain tension on the sidewall. Precoating with polyester or epoxy eliminates the coating step and VOC concerns.

For two-piece cans, the end production process includes converting the shell and applying seaming compound. Convenience ends also require formation of the pull tab or ring and a riveting operation that attaches it to the shell to produce a finished end. Historically, seaming compounds have been solvent-based, but water-based materials are capturing a growing market share due to environmental concerns and ever stricter regulation of VOC emissions.

With the advent of polyester inks with water-based overvarnish crosslinked with melamine resin, aluminum for beverage cans no longer needs conversion coatings to protect the surface [19].

Easy-Open Ends

Easy-open ends range from the familiar stay-on tab (SOT) found on beverage cans to ring-pull ends like the ones used on pet food and heat-sealable flexible membranes.

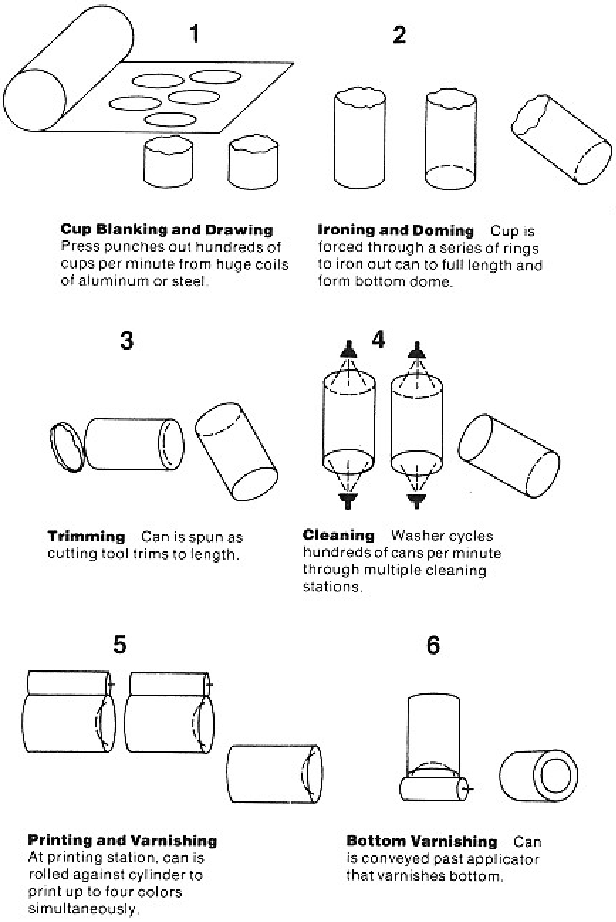

Figure 10.5.
Can bodies without seams are made by deepdrawing sheet metal in a multistep process that begins with (1) cup blanking and drawing and continues through (2) ironing to full length and doming, (3) trimming, (4) cleaning, (5) printing and varnishing of the outer circumference, (6) bottom varnishing.

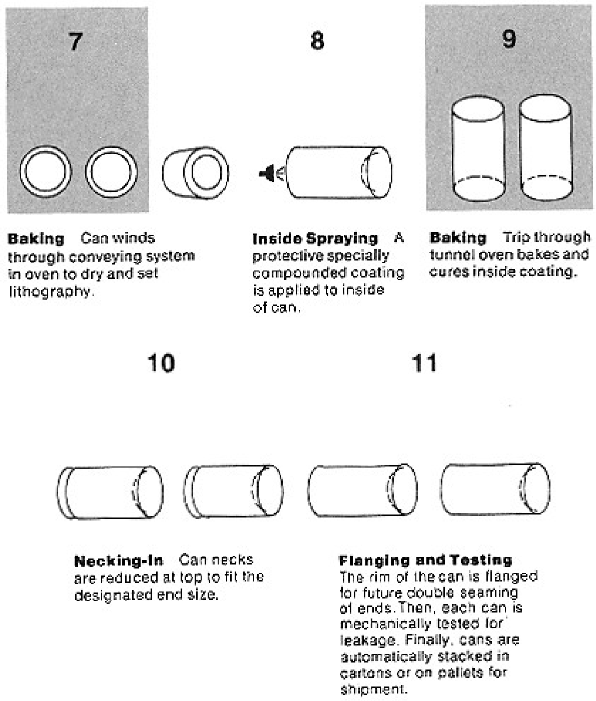

Figure 10.5.
(continued). (7) Baking to dry and set the ink and varnish, (8) inside coating, (9) baking to cure the coating, (10) necking in, and (11) flanging and testing.
(Source: National Can Co., now American National Can Co., Chicago, used with permission.)

Although initially made of aluminum and used on both steel and aluminum bodies, steel designs now are widely available.

One new bevcan end is a tabless design with a raised conical profile and central 0.75-in.-diameter (19.1-mm) pour spout [20]. It is opened by pressing downward on a circular panel which pops inward without leaving any hazardous edges. Although currently being made in aluminum, the end also could be produced in steel [21].

A new SOT with a noninvasive tab has been developed for products like enteral feeding formula. Opening action differs somewhat from traditional SOTs and the tab doesn't dip into the product [22].

Recent advancements in easy-open membrane lids, which simply peel away and often are teamed with a friction-fit plastic lid for protection in the distribution chain and resealability, include a retortable seamed-on style [23].

Types of Cans

While beverage and sanitary food cans account for the majority of the metal-container market, there are a number of other important can styles.

Aerosol Cans

Metal aerosols are a case in point. The same materials that are used for metal food containers can be used for aerosol cans. However, certain conditions, peculiar to these pressurized containers, must be taken into account.

To ensure container integrity under the internal pressure, three-piece cans for aerosols tend to use welded side seams. However, increasingly, packagers of aerosol products are specifying two-piece cans made by D&I or impact extrusion methods (see page 343, 352). Careful attention to gauge and temper of the metal also is essential to prevent distortion.

Interior coatings for aerosol cans not only must withstand the effects of the product, but also the propellant. If incompatibilities exist, the lining might strip away, getting into the solution and eventually clogging the valve. If this problem occurs after large quantities of product have been sent into the market, the result can be catastrophic. Products like shave creams and detergents that contain sodium lauryl sulfate have been known to do this.

Other ingredients like starch and polyvinyl alcohol may pit the enamel, causing eventual perforation of the can. This condition is hard to detect, and test packs must be examined very carefully under a strong glass, especially at the liquid surface line.

The three main types of enamels used in the interiors of aerosol containers are vinyls, phenolics, and epoxies. The vinyls have good flexibility for fabrication, but are rather poor in process resistance. Chemical resistance will vary depending on the product. Epoxies generally are good in all respects but more expensive than the vinyls or the phenolics. Perhaps the most useful enamels are the phenolics. Although brittle and somewhat troublesome for the can manufacturer, they process very well and have good chemical resistance to a wide variety of formulations.

It must be emphasized that there is no substitute for an adequate test program to select the interior coating for aerosol cans. Tests should be made not only at room temperature for the expected shelf life of the product, but also at elevated temperatures. However, it is easy to be misled by accelerated tests, which are not equivalent to actual storage conditions.

Time is an important ingredient in the final test result, and two years is not too long a period to look for trouble. It is wise to keep in mind that any subsequent change in the product, no matter how insignificant it may seem, should prompt a new series of tests before large-scale production begins. Even a change of suppliers for the same ingredient may upset the compatibility balance, and a change in the process, which alters the amount of air in the product, has been known to cause problems.

Friction-Plug Cans

The familiar paint can is an example of a friction-plug container. It is made in sizes from 1/4 pt to 1 gal (118 ml to 3.8 L). There are single and double friction plugs. The former are used mainly for powders and pastes; while the latter offer a much tighter seal for liquids. When this can is used as an outer shipping container, the cover is tacked in several places with solder or special metal clips.

Cans with Threaded Closures

Screw-top cans are containers with threaded closures. Rectilinear shapes are called F-style (first used for Flit insecticide) and are produced in 1/4-pt to 2-gal (118-ml to 7.6-L) sizes. Like round cans, dimensions traditionally are designated by three-digit numbers indicating inch and sixteenths of an inch. The first two numbers given describe the base, while a third specifies height.

Another can style with a threaded closure is a cone-top round in sizes from 3 oz to 1 qt (89 to 946 ml). Larger sizes, usually 5 gal (18.9 L), have a square footprint (see Figure 10.6).

A wide variety of threaded spouts and applicators are stocked by can manufacturers. The size of the closure, which is listed in inches and fractions, refers to the outside of the threads on the container, not to the cap. These

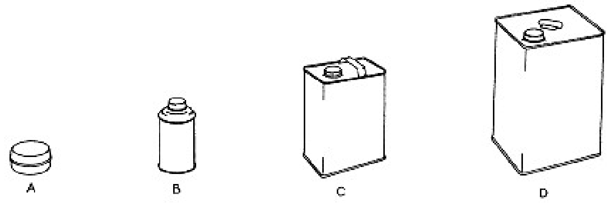

Figure 10.6.
Metal containers offer a range of styles: (A) seamless can with slipcover; (B) cone-top round can with screw top; (C) oblong 1-gal (3.8-L) container with strap handle; and (D) 5-gal (18.9-L) square can with ring handle.

sizes bear no relationship to the screw threads on glass containers, which are described in mm. Since there are no industry standards for thread profiles or helix angles, the caps from one manufacturer may not fit containers from another. Caps and containers must be purchased at the same time from the same source to ensure a good fit.

Slipcover Cans

Shallow cans with slipcovers are made by blanking and drawing tinplate to the proper size, and hemming or curling the edge. The sheet metal can be attractively lithographed before it is formed, with due allowance for the distortion that takes place in forming. Examples of this type of container are ointment and shoe-polish tins.

There are still markets for highly decorated and lithographed metal boxes, although these beautiful slipcovered containers have greatly decreased as the labor-intensive cost of making small runs has soared and other types of mass-produced containers have developed decorating techniques that are regarded as adequate.

Contour Cans

The desire for product differentiation is generating interest in new can shapes. Virtually every can converting equipment maker in the world has spent a good bit of the nineties and considerable developmental dollars working on can-shaping technology.

Just beginning to be commercialized are cans with textured surfaces or nonround profiles created by mechanical, pneumatic, and/or hydraulic forming processes [24].

Another forming process, similar to blow molding plastic containers, begins with a welded tube which is placed in a mold. Air pressure expands the metal according to the shape of the mold and the can is ejected. Although aluminum is tougher to shape because it is less stretchable and work hardens, the process reportedly is compatible with two-piece can bodies [25].

A few contoured cans began to appear on U.S. store shelves in the midnineties. In 1997, Coca-Cola Co., Atlanta, test marketed a two-piece flared aluminum can reminiscent of its glass bottle silhouette [26].

Decorating

The outside of a can may be decorated by silk screening, offset flexography (dry offset), offset lithography, or labeling via glue, pressure-sensitive, shrink, or heat-transfer methods (see Chapter 12, Labeling and Decorating). The direct decorating methods enable designers to use the reflective nature of the metal as a design element. Impact-extruded aluminum containers, for example, can be produced with a brushed finish.

Paper labels provide the lowest cost with the greatest flexibility, an important consideration for food processors that generally pack under many brand names. Thus, cans are packed and stored "bright" and labeled to order in the off-season.

Film labels, typically made of polypropylene or shrinkable PVC and applied with hot-melt adhesive or heat-shrunk into place, are being seen more frequently especially for promotions as packagers take advantage of the vibrant graphics and other potential differentiating features available like temperature- or light-sensitive ink and holographic images.

Eliminating the halo commonly found around heat-transfer labels is a process that marries a new material and machine to label glass, plastic, or metal containers at 500 per minute. The process varies some depending on container material but typically includes container preheat, image transfer, and heat cure [27].

However, it should be noted that on-line labeling of any kind could be a limiting factor on a production line because even the fastest 1,500-perminute labelers are slower than the top speeds of today's can filling and closing equipment [28].

Lithography, usually done in the flat, before the sheet is formed into a can, typically is selected for nationally branded merchandise. It allows more intricate colors and graphics than silk screening and provides some protection for the can. If required, a base coat, generally light in color, is applied first and dried by passage through a long gas-fired oven or high-intensity UV-curing unit. Next graphics are printed, typically one color per pass, although it is now possible to link presses in tandem by adjusting ink tack and setting each color with a brief hot-air, flame, or UV treatment before the next one is laid down. Cost depends on the number of colors. Embossing can heighten the decorative effect for luxury products.

Artwork for can sheet that is printed before it is formed must be designed to compensate for the finished container shape and seam if there is one. With today's high filling-line speeds and necked-in diameters on aluminum beverage cans, added abrasion resistance is being provided by polyester inks plus a water-based overvarnish cross-linked with melamine resin [29].

Offset flexography (also known as dry-offset) is used to decorate round cans. Here, the total design in multiple colors is assembled at one time on cylinder and then transferred to the can. While this technique is not truly process printing, great ingenuity has been applied in adapting halftone artwork.

Aluminum Trays

Shallow trays made from thin-gauge aluminum sheet have found widespread use in frozen food dinners and baked goods. Available in round, square, oblong, and some odd shapes, plus a myriad of sizes, most have crinkled sides. Smooth sides can be made, but tool costs and, thus, piece price are much higher.

There are three general types of closures: (1) a vertical flange, which is folded over a flat board cover; (2) a horizontal flange, to which a cover is heat-sealed, and (3) a horizontal flange with a hood cover which is crimped under the flange. Covers are made of a paperboard disk, sometimes with a transparent window; a flat hood of aluminum with a downward flange that can be curled under the rim of the tray, and raised hoods of aluminum or clear plastic sheet for products that are higher than the tray.

Today, this type of container also is made from plastic and paperboard and is discussed in Chapters 8 and 2, respectively.

Collapsible Tubes

An American portrait painter, John Goffe Rand, looking for a better container for his oil colors, extruded the first metal tube of tin in 1841. The first manufacturing plant in this country was established in 1870 and up until the turn of the century, only two additional companies were formed for this purpose.

Around 1895 toothpaste was offered to the public in tubes. It was such a great success that other semifluid products were tried in these packages. There has been continued growth. In 1996, industry sources estimate there were roughly 3 billion tubes made in North America. Of these about 721 million were metal with the rest equally divided between plastic and laminate structures (see Chapter 8, Plastics).

Markets using tubes include dentifrices, pharmaceuticals, cosmetics, and household/industrial with pharmaceuticals being the largest user of metal tubes and cosmetics having the largest share overall.

Of the metal tubes produced in 1996, more than 99 percent were aluminum with tin and lead each accounting for fractions of a percent.

The collapsible metal tube is a functional container that permits controlled small amounts of liquid and paste-like products to be dispensed easily. For multiuse products the closures are screw caps. "Blind end" tubes, which have no dispensing hole in the spout and are used for single applications, usually forego a cap. An advantage of the metal tube is that it provides minimum risk of contamination during dispensing, since the tube does not suck back when released. Lightweight, reasonably unbreakable, and compatible with high-speed automatic filling operations, tubes have a smooth surface, which is easily decorated in multiple colors with good fidelity. High gloss colors, embossed shoulders, and special closures/fitments offer both marketing and functional advantages.

Any ductile metal that can be worked cold is suitable for collapsible tubes, but the most common is aluminum. Aluminum work-hardens when it is formed into a tube, and must be annealed to give it the necessary pliability. Aluminum also work-hardens in use, sometimes causing tubes to develop leaks.

Tin is the most expensive, at least in the larger sizes, and lead is the cheapest. Very small tubes can sometimes be made more economically out of tin because it is more easily worked than the other metals, and the cost of material becomes less significant as the size gets smaller. The tin that is used for this purpose is alloyed with about 0.5 percent copper for stiffening.

The metal for tubes is received as pigs and cast into slabs preparatory to rolling into sheets. Slugs about the size of coins are punched from these sheets, tumbled, lubricated, and sent to an impact extrusion press with a shallow female die and a male die shaped like the inside of the tube and somewhat longer than the unit to be produced. When the die closes on the slug with considerable pressure, the metal squeezes out between the two parts, hugging the inner die as it moves rapidly out around it. When the die separates, the tube is blown off with compressed air (see Figure 10.7).

Subsequent operations, such as cutting the thread, reaming the orifice, trimming to length, decorating, and lining, are performed on another machine.

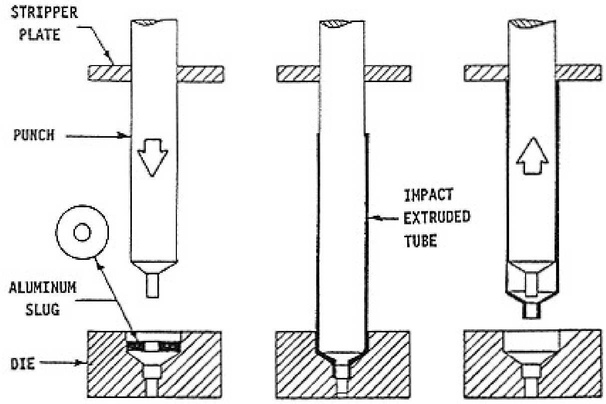

Figure 10.7.
A slug of aluminum is shown in place in the lower half of the impact extrusion die on the right. When the die closes, the metal is forced up around the upper part of the die as shown on the left. This method is used to make collapsible tubes and two-piece containers. (From Soroka, W. Fundamentals of Packaging Technology, Institute of Packaging Professionals, Herndon, Virginia, 1995. Reprinted with permission.)

After trimming, aluminum tubes are annealed for a short time in ovens at temperatures between 900 and 1,200 F (482 to 649 C). After decorating, the tube is carried through an oven to dry the coatings, and then the closure is applied. The end opposite the closure is left open to its full diameter for filling, and the tubes are packed into nested boxes to preserve the cylindrical shape of the body. They are easily damaged at this stage and must be packed in sturdy boxes and handled rather carefully.

The shoulder of a metal tube can be embossed with a design or legend in the extrusion die but cannot be printed easily. Embossing of the side walls of tin or lead tubes also is possible, within limitations, using special tools for this purpose.

The enamel coating does not extend onto the shoulder, but a matching color can be sprayed on. Sometimes clear lacquer is used to prevent tarnishing, particularly with lead tubes. An attractive brushed finish can be applied to the shoulder of aluminum tubes. Most tubes have an enamel base coat applied to the side wall by roller coating. Up to five colors can then be printed simultaneously by the offset process. Best results are obtained if the colors do not have to be registered too closely. The base coat usually is the lightest color with the printing inks in the darker tones. Protective coatings can be applied over the ink, but with good gloss inks are usually unnecessary.

Preparation of final artwork for printing should be left to the tube manufacturer so the allowance for wrapping the printing plates around the printing roll will be correct. The coat can be formulated, if desired, so that it is easily peeled off. This is useful for prescription items, for example, if it is desirable that the druggist remove the identity of the product and replace it with the prescription information furnished by the doctor.

If the product is not compatible with bare metal, the interior can be flushed with wax-type formulations or with resin solutions, although resins and lacquers generally are sprayed on. Care must be taken to prevent clogging the orifice with the lining material, especially where elongated nozzle tips are employed.

Wax linings most often are used with water-based products in tin tubes. Phenolics, epoxies, and vinyls are used with aluminum tubes, providing better protection than wax, but at a higher cost. Phenolics are most effective with acid products; epoxies protect better against alkaline materials.

Screw caps are available in various styles under such descriptive names as fez, mushroom, reverse taper, flowerpot, and eye tip. Some caps are made of metal, but the majority are plastic and are available in virtually any color (see Chapter 13, Caps and Seals).

Applicators, which can be either integral or separate parts of the tube, come in a variety of shapes, including pile and vaginal pipes; and ophthalmic, nasal, mastitis, and screw-eye tips. For volatile products or where sterility is important, tubes can be made with a blind opening and a screw-eye or pointed cap can be provided to puncture the tip when the product is to be used. Tubes with plastic necks prevent the accumulation of gray spots and streaks of metal particles and oxides, which are the residue of the tube fabrication processes, the grinding action of the cap on the metal threads, and any product accumulation. Some single-use tubes have neither neck nor cap; they are opened by tearing off the folded end. Break-off tips also can be used for the same purpose.

The tube is filled through the bottom, and the end is then flattened and folded to form a seal. A folded piece of stiff metal, called a clip, is sometimes placed over the end and tightly closed to keep the tube from leaking when pressure is applied for dispensing. More often, however, a clipless closure is made by folding the metal several times and crimping it (see Figure 10.8). Heat-setting sealants can be applied as an inside or outside coating near the tube end. When heat is applied after closing, the coating softens and flows to make a more positive seal. A welded seal also is available.

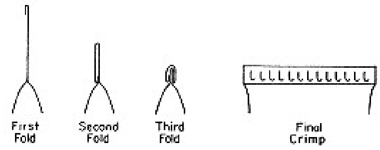

Figure 10.8.
Sequence of folds in closing the bottom of a metal tube is shown.

Steel Drums and Pails

In 1902 the Standard Oil Company (now BP America Inc., Cleveland, Ohio) began replacing wooden barrels with its Bayonne steel barrel. It was bilged and shaped like its wooden counterpart.

The straight-sided steel drum, first introduced in 1907, was made of 16-gauge (0.0533 in. or 1.4 mm) terneplate, a lead and tin dip-coated steel, with soldered side and chime seams. The welded side seam was first produced by C. T. Draper, who also invented the five-ply double-seam chime. These two innovations gave a notable boost to steel containers, since they curtailed the leakage problems of riveted barrels and reduced costs.

Credit for the 55-gal (208-L) drum as we know it today is usually given to Nellie Bly. Her American Steel Barrel Company, which she built up after the death of her husband, became the largest single producer. By 1920, hand painting was replaced by automatic painting and baking of enamel coatings.

The need to reduce costs soon resulted in the development of the 55-gal (208-L) drum made from 18-gauge (0.0428 in. or 1.1 mm) steel with welded seams.

In 1914, the first true 5-gal (18.9-L) steel pail was introduced. It was promoted by Myrtle Stevens Bennett, a widow that took over a company later called Wilson & Bennett. Under her leadership, the firm became a major producer of steel drums and pails. It installed the first electric side-seam welding machine in the United States.

The first World War created a heavy demand for containers that has continued to an annual output in 1995 of 33.4 million steel drums valued at $684 million and 92 million steel pails valued at $174 million [30].

Regulations

Light shipping drums for shipment of nonregulatory products, also known as single-trip drums, are specified in Rule 40 of the *Uniform Freight Classification* for rail shipment and in the *National Motor Freight Classification* for trucking (see Chapter 20, Laws and Regulations). Drums for hazardous materials are governed by the U.S. Dept. of Transportation, Washington, D.C., as are all hazardous materials packaging (see Chapter 20, Laws and Regulations).

Manufacturing

Both cold- and hot-rolled steels are used to make drums. Although coldrolled is cleaner and easier to coat with resin, hot-rolled is sometimes preferred for certain types of treatment. Acid pickling, detergent scrubbing, sand blasting, and shot blasting frequently are used to prepare the steel for fabrication.

Bottoms and tops are blanked out of sheets. Bodies are sheared to size and then rolled in a machine until the edges come together to form a cylinder. After the joint is butt-welded and the slag from the welding operation is removed, the joint is flattened to be flush with the rest of the body. Flanges, beads, and rolling hoops are then rolled into the shell, where necessary. The lining material is sprayed on the different parts separately, and baked on. A seam compound is flowed in around the edges of the head and bottom, and they are joined to the body by spinning the edges together to form a fivelayer chime. The outside of the drum is then painted, silk-screened, or lithographed.

Some resistance to corrosion is provided by phosphatizing, which is a chemical treatment of the surface of the steel. For better protection or for products that need a better coating, phenolics are widely used. They are very effective against acids, which are the most troublesome materials to package in metal. Low in cost, but brittle, their resistance to alkalies is generally poor. Vinyls are very good with alkaline materials, flexible, and reasonable in cost. Epoxies have good resistance to alkalies and fair resistance to acids. They are flexible, but tend to become brittle with age when in contact with certain products, and be a bit higher in cost than the others. Really stringent applications may opt for stainless steel although it carries a significant upcharge (see Table 10.5).

It is important that lining materials be properly cured. If undercured, they will not have the proper chemical resistance and if overcured, they tend to be brittle. Other available coatings include polyvinylidene chloride, polytetrafluoroethylene, vinylidene chloride-acrylonitrile copolymer, styrenebutadiene, neoprene, and plastisol. Polyethylene is widely used, but usually in the form of a loose liner, which is shaped to fit closely to the interior of the drum.

Steel drums are made in tight- and open-head styles (see Figure 10.9). Tight-head drums usually have two flanged openings: a 2 in. (5.1 cm) and a 3/4 in. (1.9 cm) positioned at opposite sides in the head of the drum, or one in the

TABLE 10.5. 55-Gal (209-L) Drum Styles and Costs.

Style	Cost
Stainless Steel Open-head, Lever-lock	$751
Stainless Steel Closed-head	$664
Stainless Steel Open-head, Bolt-ring	$628
Standard Steel Open-Head, Bolt-Ring	$ 72
Standard Steel Closed-head	$ 57

head and the other in the middle or the end of the body, on the opposite side. The openings are threaded and fitted with screw plugs and rubber or asbestos gaskets. Sizes given refer to U.S. Standard Pipe Thread sizes. The small opening is for venting; the large for filling and the attachment of a spigot.

Open-head drums have a loose cover with a gasket in the channel which is formed around the edge. This makes a tight seal against the rim of the drum. A bolt-ring or lever-lock ring is provided to draw the cover down tightly on the drum and hold it in place for shipment. The lever-lock is more expensive,

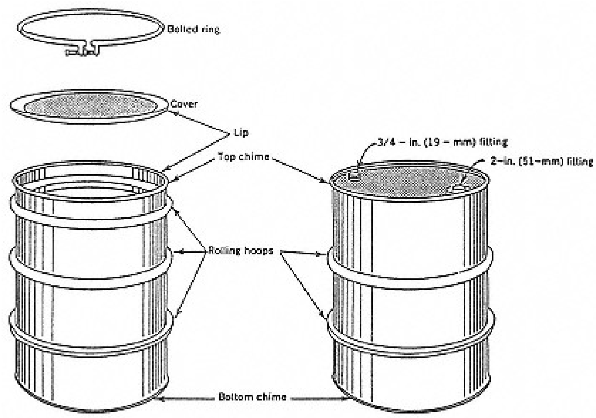

Figure 10.9.
Drum styles include (l-r) open-head and tight-head. The former features a removable cover; the latter a permanently attached cover with bung openings for access.
(Source: Institute of Packaging Professionals, Fundamentals of Protective Packaging Course, 1990)

but if the drum will be opened and closed frequently, it is worth the added cost. Rolling hoops are formed by "beading" the side wall at two equally spaced points. Although originally intended to provide for easy rolling, hoops also greatly stiffen and strengthen the drum.

Drum and Pail Inspection

Inspection of drums and pails for quality requires a flashlight and a Wheatstone Bridge for checking continuity of the inside coating. A Lenox Borescope is a good supplement.

In taking random samples for testing, the square-root-plus-one formula for sampling provides a rather small sample for a whole truckload of containers. Chime cuts should be submitted by the supplier, at least one per 500 containers.

Width and height should be checked for conformity as well as the head and body openings and compared with a sample from a previous shipment or against purchasing specifications. Check thickness of metal in the head, bottom, and body of the samples. Check for visual defects such as dirt, rust, dents, and voids in the coating. To check continuity of the inside coating, use the Wheatstone Bridge. Fill the drum or pail with water to which has been added 2.5 oz (71 g) of sodium chloride (common salt). Insert the platinum electrode in the water and clamp the other to the outside of the container to a spot where paint has been scraped away to bare metal. Any reading of less than a million ohms is cause for rejection. Any deflection of the needle indicates porosity and the drum should be rejected.

Another test that requires no equipment, but is more difficult to perform, is to wipe the coated container surface with a cloth saturated with an acidulated ferrocyanide solution. If any blue color shows on the cloth, it indicates discontinuity of the coating and is cause for rejection. Both bodies and ends should be tested in the impact areas with this chemical solution.

To determine if a lining material is suitable for your product, obtain test cups and covers from a drum supplier. These are metal cups about the size of a soup bowl, coated with the lining material to be tested. Product is put into the cup, and the cover is applied. After storage at an appropriate time and temperature, the cups are emptied and studied. The line of the top product level, in particular, should be examined for corrosion. Several different linings should be tested at the same time for comparison.

Steel Pails

There are many sizes and styles of pails, some with bails, or handles, and some without, both straight-sided and tapered, tight-and open-head, single-and double-bead, necked-in top, and ducked-in bottom, to name a few. Pails

TABLE 10.6. 5-Gal (18.9-L) Pail Styles and Costs.

Style	Cover/Dispensing Option	Cost
Open-head/Nested	Metal Lug	$ 7.55
Open-head/Nested	Metal Lug/Push-pull Spout	$ 7.55
Open-head/Nested	Metal Lug/Screw Cap	$ 7.55
Open-head/Nested	Metal Lug/Flexible Spout	$ 7.55
Closed-head	Screw Cap	$ 9.81
Closed-head	Screw Cap/Push-pull Spout	$10.30
Closed-head	Phenolic Liner and Flexible Spout	$10.77
Closed-head	Bung Fittings	$10.94

come in a range of sizes from 1 to 10 gal (3.8 to 37.9 L). Several types of closures, spouts, and other fittings can be supplied to suit the requirements of the product and will affect cost to some degree as shown in Table 10.6. Most of the interior coatings that are used on drums also can be applied to pails, and the same facilities for exterior decoration are available for the smaller containers.

Thickness of metal is left up to the customer and will depend on how severe the service is expected to be. Small sizes are commonly made

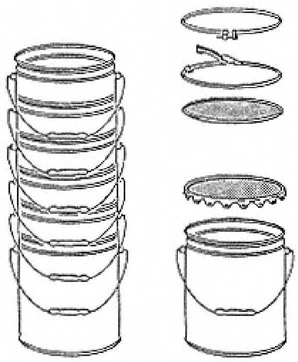

Figure 10.10.
Tapered open-head pails can be nested when empty, requiring less shipping and storage space. Pails can be combined with a variety of cover options including lug and locking ring. (Source: Institute of Packaging Professionals, Fundamentals of Protective Packaging Course, 1990, used with permission)

TABLE 10.7. Standard Pail Diameters.

Inside Diameter		Volume	
in.	cm	gal	L
6	15.2	1	3.79
8	20.3	2.5	9.46
11.25	28.6	3-7	1.4-26.5
13-15/16	35.4	7+	26.5+

from 26-gauge (0.0159-in. or 407.7- m) steel, and the larger ones most often are made from 24 gauge (0.0209 in. or 536 m). The trend is toward lighter gauges, however, and 5-gal (18.9-L) 28-gauge (0.0129-in. or 330.8- m) straight-sided and nesting pails with a 26-gauge (0.0159-in. or 407.7- m) lug-style cover are now authorized by motor carriers and the railroads.

Nesting pails have become dominant at the expense of the straight-sided containers because when empty they occupy one-third the storage space (see Figure 10.10). Pail heights vary according to capacity and style, but diameters have been standardized (see Table 10.7).

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Chapter 11— Pressurized Packaging

History

An aerosol is a self-pressurized packaging form consisting of a metal or glass container having an attached valve that, when activated, dispenses liquid products or fine suspensions in sprays, streams, gels, foams, lotions, or gases. The term *aerosol* also denotes, scientifically, a suspension of small particles in a liquid or gas. Traditionally, the packages have been powered by pressurized gases.

In recent years, the original containers have been joined by others that (1) are pressurized simply by an elastic sleeve, (2) separate delicate products from the propellant by means of a solid freely moving piston, and (3) eject the contents mechanically by pumping a button or trigger, which applies pressure only to the container pump.

Various sizes and types of containers are available, too, from purse sizes holding a few grams of perfume or medicines to 24-oz (710-ml) cans filled with cleaning and sanitizing liquids. Between these extremes is a wide choice of two- and three-piece tinplate cans, seamless aluminum and stainless steel cylinders, and glass. Plastic containers have been tried, but have not yet been successful in gas-pressurized aerosols.

Color and decoration can be applied several ways, and the creative designer has ample opportunity to make these packages very attractive and appealing.

The aerosol originated in 1923 when Eric Rotheim of Oslo, Norway, created a sprayable ski wax and enclosed it in a heavy metal container fitted with a needle valve for dispensing and powered by butane or vinyl chloride propellants. It took a second World War, though, to make the idea practical.

At the start of the war in the Southwest Pacific, there were more casualties from disease than from combat. So, the U.S. Department of Agriculture (USDA), Washington, D.C., was asked to develop a better insect control system. After several failures, Lyle Goodhue and William Sullivan of USDA's Beltsville, Maryland, laboratory discovered that a spherical steel container filled with insecticide could deliver an aerosol dispersion that remained airborne for 5 min or more and was effective against both airborne and crawling insects. Throughout the war, these "bug bombs" were used from the South Pacific to Europe and were credited with inhibiting major outbreaks of disease among both civilians and armed forces personnel.

The massive welded-steel deposit-returnable container, however, stifled the potential civilian market until it was learned that a mixture of certain propellants reduced the pressure in the container, permitting the substitution of less costly canisters. A modification of the beer can was developed for this purpose, and in November 1946, the first commercial carload shipment of these containers was made by Crown Can Co. (now Crown Cork & Seal, Philadelphia). In 1947, Continental Can Co. (now also part of Crown Cork) introduced a three-piece can with a concave top and bottom and soldered valve. The first hydrocarbon propellant was used in 1953 when Dr. Daniel Terry developed Bon Ami Window Cleaner using isobutane as the propellant.

Since 1946 when about 5 million units were sold, the aerosol business has soared, reaching a total of slightly more than 3 billion containers of all types in 1996 [1]. The overwhelming majority, about 2.62 billion, are tinplate cans. The remainder include 368 million aluminum cans and 13 million coated and uncoated glass containers. See Table 11.1 for annual shipments by enduse product [2].

TABLE 11.1. 1996 Aerosol Shipments.

Category	Quantity (million)
Personal Products	1,016.6
Household Products	851.8
Coatings and Finishes	453.8
Automotive/Industrial	417.0
Insect Sprays	205.0
Food Products	227.9
Animal Products	6.5
Miscellaneous	32.3
TOTAL	3,210.9

Source: Chemical Specialties Manufacturers Association, Washington, D.C., used with permission.

Advantages and Disadvantages

Pressurized containers are certainly more expensive than conventional cans, bottles, and jars, but offer many advantages for certain types of products that, in fact, owe their very existence to the aerosol delivery. Among these are hair sprays, shaving creams, windshield deicers, and artificial snow. Other products are simply much more convenient for the consumer in a pressurized container; for example, insecticides, room deodorants, perfumes, lubricants, and touch-up paints. The pattern and size of the minute spray particles can be varied to suit particular purposes. Finally, aerosols are sanitary, tamper-resistant, easy to use, cost effective, environmentally sound, and recyclable.

Although the aerosol has added an important dimension to packaging, it does not automatically bring success in the marketplace. This packaging system must satisfy a real need for the consumer, or it will be rejected. Several examples of poorly conceived products can be cited. Pressurized chocolate syrup was irresistible to children, but resultant messes infuriated parents. A coffee concentrate that required refrigeration and had an inferior flavor was a quick casualty. Toothpaste that was too thin to suit popular tastes and often failed to dispense because of cavitation within the can soon disappeared from the shelves, and a barbecue sauce was taken off the market when the cans failed due to corrosion at the side seam.

Many products are in standard 211-diameter (2-11/16-in., 6.83-cm) steel cans, which are convenient and economical. However, designers have created a host of other sizes in steel, aluminum, and glass containers. Perhaps the most ingenuity has been shown in the configuration of dispensing buttons, valve styles, and overcap design. While some aerosols are still labeled, the trend is to lithography in up to five colors, as discussed later in this chapter.

Aerosols can pose a hazard if punctured or incinerated, and it is important that the packager puts the necessary warnings on the label on how to dispose of the containers. Aerosols containing flammable products should be charged with a nonflammable propellant and should not be used near high heat or open flames, which might ignite the mist or break it down into hazardous gases.

Aerosols can lose some propellant and/or product before purchase, but it is usually less than 1 g (0.04 oz) per year, and overfilling by this amount can compensate for the loss. Normally, the gasket in the valve is designed to swell, so that the rate of loss decreases as time passes. The aerosol industry considers 0.5 percent to be the maximum allowable loss from a container in one year.

One advantage of aerosols that is often overlooked is the protection of the contents from outside influences. Whereas some containers take in air and/or moisture as the contents are used, standard, pressurized packs never allow the atmosphere to enter or mix with the product. Thus, the consumer can be assured that the product will always be as pure as when it left the factory, and the manufacturer can be confident that no oxygen will get in to degrade the formulation.

Principles of Operation

Propellants for aerosols consist of either liquified or compressed gases. In a typical liquid-propellant aerosol, the load of liquid propellant and liquid product occupies the lower seven-eighths of the container and gaseous propellant fills the remainder at the top. All contents are under pressure. If the liquid propellant is insoluble in the product, the resultant composition is called a three-phase system. If the liquid propellant is soluble in the product or a compressed gas is used as a propellant, it is termed a two-phase system (see Figure 11.1).

For aerosols used in an upright position, a dip tube goes from the valve down into the liquid product. For aerosols designed to dispense upside down, the dip tube is omitted. When the valve is opened by depressing the actuator, the gas inside the container exerts pressure in all directions, forcing the liquid up the dip tube and out through the valve (see Figure 11.2). If the liquid propellant has dispersed homogeneously into the product either as a solution or

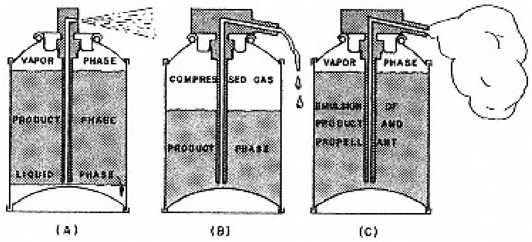

Figure 11.1.
In a three-phase system (A), the liquid propellant is in a layer separate from the product with propellant vapor on top. With a compressed gas that does not liquefy (B) or if the propellant mixes with the product (C), it is a two-phase system. Different forms of product also are shown, with a spray being produced by a suitable actuator at A; a solid stream at B, where the product and propellant do not mix; and a foam at C, resulting from a mixture of product and propellant combined with a large orifice in the actuator.

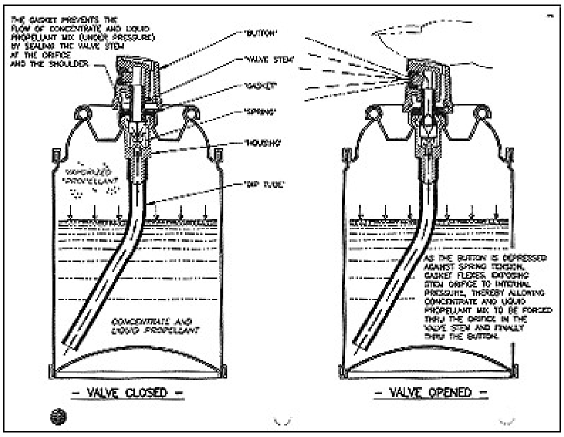

Figure 11.2.
When the valve is closed (left) the gasket prevents the flow of concentrate and liquid propellant mix (under pressure) by sealing the valve stem at the orifice and the shoulder. The valve opens (right) when the button is depressed against spring tension, flexes the gasket, and exposes the stem orifice to internal pressure, forcing concentrate and liquid propellant mix through the orifice in the valve stem and finally through the button. (Source: Precision Valve Corp., Yonkers, New York, used with permission.)

an emulsion, it will turn to gas as the product is ejected, breaking the liquid into tiny droplets in the familiar spray mist. A 1-sec burst of a typical spray may produce more than a million particles, depending upon spray rate, actuator orifice, pressure, propellant percentage, surface tension, and product density.

After ejection, a small amount of liquified gas propellant will evaporate inside the package to take the place of the liquid that was dispensed, increasing the gaseous portion by that amount. When a liquid propellant changes to gas, it will occupy as much as 250 times its original volume. Eventually, little liquid will remain in the container, and most of the space will be occupied by gas, but the pressure will always be about the same, as long as there still is some propellant in liquid form.

In some cases, for example, if the product has a greater specific gravity than the propellant, propellant and product do not mix, but separate into layers. Pure product is then forced up the dip tube when the valve is opened, and none or very little of the propellant goes with it. The product can be ejected as a stream, or the valve and actuator can be designed to create a velocity and shear that breaks the stream into a spray, although it's not as fine as one with dissolved propellant gas. A "vapor tap," consisting of a small hole in the side of the valve body, also can be used to help atomize the product. A small amount of gas escapes from the headspace through this vapor tap and

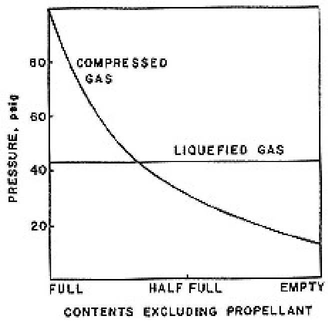

Figure 11.3.
Liquefied gases such as hydrofluorocarbons and hydrocarbons maintain a constant pressure until the contents of the can are used up, as long as any liquid propellant remains. Compressed gases such as nitrogen and carbon dioxide will show a drop in pressure as the can is emptied, due to expansion of the gas into the larger headspace. This typical curve will vary according to the gas used and the space occupied.

goes into the product as it passes through the valve to assist in breaking up the liquid.

In a compressed-gas aerosol, if the product does not dissolve or emulsify in the propellant, the product is usually ejected as a stream when the valve is opened. Pressure in a compressed-gas aerosol decreases as the contents are dispensed and open up a larger headspace (see Figure 11.3). An important point to be noted here is that both the propellant, whatever kind it is, and the product interact physically, which is a determining factor in the end result.

Selection Criteria

The choice of the container, valve, and actuator depends on the type of product and the desired end result. Thus, shaving soap that is to be dispensed as a foam requires a package different from that for a hair lacquer intended to come out as a fine spray.

The best approach is to start with a consideration of the product formula: Is it miscible with the propellant? Will it form a separate layer in the container? Or will it be somewhere in between, such as in a suspension or an emulsion?

This then brings up the question of the propellant: Will it be a liquefied propellant or a compressed gas like nitrogen or carbon dioxide? If a constant pressure is necessary until the package is completely empty, then a liquefied propellant is dictated. Food products and some pharmaceutical preparations require a propellant that has been cleared by the Food and Drug Administration (FDA), Washington, D.C., generally nitrous oxide.

The type of formulation also may determine the filling method. Originally, products and propellants were cold filled, a process in which both the product and propellant were chilled below the boiling point of the propellant and a measured amount of each was put into the container. Then, as quickly as possible, the valve was applied and crimped into place. The completed package was carried by conveyor through a hot-water bath, to detect any leakers, which would bubble under the water. This technique was relatively slow and is rarely used today.

More common currently are under-the-cup (UTC) and pressure filling methods. In the first method, after filling the product, the valve is placed in the can, but not crimped. Propellant is then forced into the can under the valve cup in a sealed chamber and the cup is then crimped. This method is fast and adaptable to most products.

In pressure filling, product is filled and the valve is crimped in place. Propellant is then forced through the valve into the container. Depending on the type of valve used, this can be rather slow. However, development of specialized rotary fillers has increased the speed, today, to nearly that of UTC fillers.

The character of the spray or foam will depend in large part on the combination of valve and actuator. For example, a wet spray made up of droplets larger than 50 m (0.002 in.) in diameter that will not blow away is desirable for coating surfaces, whereas a fine, dry mist is better suited for room deodorants. The type of spray can be controlled by choosing the proper orifice sizes and taper in the actuator button, the valve stem, the percent of propellant used, and the tail piece (the valve extension that inserts into the dip tube). Some actuators are designed to provide a mechanical breakup of the spray in addition to the dispersion resulting from evaporation of propellant (see Figure 11.1).

The compatibility of the valve with the formulation is another factor that should not be overlooked. When certain products are in contact with some plastics—in a metering chamber, for example—they may leach the antioxidants and plasticizers from the plastic. In other cases, they may be absorbed by the plastic. Thus, it is extremely important to test for any interaction or absorption on a product-by-product basis.

Whether to use a container made of tinplate, aluminum, or glass, may depend on marketing considerations, but usually is determined by the nature of the formulation. After the decision has been reached, the compatibility and stability of the product should be checked very carefully with samples of the actual containers and tests should be performed under varying atmospheric conditions and for an extended period of time—at least 3 months and, preferably, 6 to 9 months.

Things to look for in the tests are the settling out of solid particles, degradation of perfume, crystal formation, lumping together of particles, container corrosion, gasket swelling, and leakage of any kind. There is often a delicate balance between the ingredients in the formulation, the propellant system, the materials and coatings in the container, and the various parts of the valve. Never fail to try them out in use under all of the possible conditions that can be anticipated. When the results are satisfactory, do not change a thing without going through the complete testing procedure again.

Suppliers also have made progress in developing containers that separate the propellant from the product (see Separated Containers, page 372). These designs are now being used for delicate food and drug items and other sensitive products that could react with either propellant or container constituents.

Summing up the various things to consider in selecting the components of an aerosol package, we have: (1) the product formulation, whether aqueous or nonaqueous; (2) method of application, as a fine or coarse mist, liquid stream, or foam; (3) the type of container—glass, aluminum, tinplate, or plastic; (4) the valve to control the rate of application and to mix the product and propellant; and (5) the kind of propellant—compressed gas or liquefied gas. We will now discuss each of these components in turn.

Containers

There are three principal types of aerosol containers: steel, aluminum, and glass. Of these, steel is by far the most popular, accounting for more than 90 percent of current production [3].

Steel Cans

Steel cans are used in all categories of aerosol products (see Table 11.1). Tinplate and electrolytic chromium-coated steel (ECCS) are used for three-piece cans, which used to have soldered side seams, but now are welded. Seamless two-piece steel cans are fabricated via a drawing and ironing process. For tinplate and ECCS bodies, plate weights can range from 55- to 90-lb (25- to 41-kg) stock, depending on can size. Ends must be heavier to withstand the pressures, ranging from 123 lb (55.8 kg) for the base ends to 135 lb (61.2 kg) for the top dome.

Standard steel cans range in capacities from 3 fl oz (88.7 ml) to about 23.7 fl oz (700 ml) nominal capacity (see Table 11.2 for different standard sizes and Table 11.3 for representative costs). However, sizes up to about 1 L nominal capacity are made in both the United States and Europe.

The nominal capacity of a can has little relationship to its real capacity, as can be seen in Table 11.2. Common practice is to fill to 85 percent of overflow capacity at 70 F (21 C). This is best determined by measuring the volume of a known weight of formula with a graduated glass pressure tube at the required temperature. This can be converted to specific gravity and used to calculate the necessary weight.

TABLE 11.2. Sizes of Representative Metal Cans.

Size	Nominal Capacity	Overflow fl oz	Capcity cm^3
202 214	3	5.07	150
202 314	6	6.76	200
202 406	6	7.78	230
202 509	9	9.98	295
207.5 701	14	16.91	500
211 413	12	14.03	415
211 510	14	16.40	485
211 604	16	18.26	540
211 713	20	40.30	659
300 709	24	48.50	795

TABLE 11.3. Cost Range of Aerosol Containers.

Container Type	$ Cost/1,000
3-piece Steel Can	120-130
Piston Can	330-340
Pouch Can	750-1000
Drawn/Ironed Steel Cans	150-450
Impact-extruded Aluminum Can	200-700
Glass, Coated	250-750
Glass, Uncoated	100-600

There are regulations covering the construction of metal cans for certain purposes administered by the U.S. Department of Transportation (DOT), Washington, D.C. Most of the containers used for household products are classified as nonspecification cans if the pressure does not exceed 140 psig (1,067 kPa) at 130 F (54 C) and if the capacity is not more than 19.3 fl oz (571 ml). The minimum bursting strength for an unclassified container is 210 psig (1,549 kPa), which is 1.5 times the pressure at 130 F (54 C).

If the pressure at 130 F (54 C) is more than 140 psig (1,067 kPa) but less than 160 psig (1,205 kPa), a Specification 2P container must be used, according to section 73.306 of the DOT regulations. The 2P can must be made of steel plate not less than 0.007 in. (178 m) thick and must withstand 240 psig (1,756 kPa) internal pressure. The standard, welded aerosol can of proper thickness and temper usually will meet this requirement and must be marked "DOT 2P."

If the pressure at 130 F (54 C) is more than 160 psig (1,205 kPa) but less than 180 psig (1,342 kPa), a 2Q container must be used. For greater pressures, an exemption must be obtained from DOT.

To protect can interiors from the effect of products known as "strippers" and "perforators," coatings called enamels are used. For example, spray starches of the PVA types are perforators; window cleaners and some shave creams are strippers. There are five enamel choices: vinyls, organosols, and combinations of epoxies, phenolics, and urea-formaldehydes.

With difficult products, multiple coatings are applied, particularly on seam areas. However, it is a generally accepted fact that cans cannot be coated so completely that no metal is exposed. There are sure to be some voids, which are often critical factors in determining an adequate shelf life. Corrosion may cause leaky cans, and unfavorable reactions between container and product may result in flakes or sediment that clog the valves. In some cases, stainless steel, usually Type 304, reportedly is used particularly for very small containers and special applications.

Aluminum Cans

Aluminum is made into one-piece containers by impact extrusion and spinning. The one-piece aluminum container is more popular in Europe than in the United States because the cost is more favorable in comparison with tinplate. However, some aluminum aerosols are now used in all of the product categories listed in Table 11.1, with the greatest number being specified for personal products where the eye appeal of polished and seamless cans is most important.

With a normal bursting strength above 300 psig (2,170 kPa), these onepiece, impact-extruded containers have the ability to withstand high pressure. In the impact-extrusion process, a slug of metal is put into a shallow die, and a punch forces the metal to extrude back over the punch. The resulting cylinder is blown off the punch and sent to a trimming operation, after which it is necked-in to form the seat for the valve cup.

Eight standard container sizes range from 35 to 66 mm in diameter (1.4 to 2.6 in.) and have the 1-in. (25.4-mm) valve hole just like the steel cans. Special sizes also are made.

The chief disadvantage of aluminum is its poor resistance to corrosion, particularly with alkalies, strong acids and, to some extent, water.

Glass Bottles

Glass is also used in relatively small quantities for aerosols in the personal, household products, and medical categories. Where elegance is required in fragrances, perfumes, and toiletries, glass is preeminent in offering a great variety of custom shapes. Its other advantage is its resistance to attack by almost all chemicals including corrosives.

Depending on end use, USP Type I, II, or III glass may be specified for aerosols with Type III being the most common (see Chapter 9, Glassware). If cases where the product would attack metal, a valve with only plastic and rubber parts can be specified.

Glass, too, has a series of standard sizes. One supplier's line of six Boston Rounds, for example, ranges from 1/3 to 4 oz (10 to 118 ml) in capacity, 27 to 55 mm (1.1 to 2.7 in.) in diameter and 57 to 115 mm (2.2 to 4.5 in.) in height. Glass containers do not have the 1-in. (25.4-mm) valve seat common to metal containers. Glass aerosols are made with 13-, 15-, 18-, 20-, and 22-mm (0.52-, 0.6-, 0.72-, 0.80-, and 0.88-in.) finishes and take valves having a metal ferrule as a base instead of a cup. The ferrule has a long skirt that can be clinched around and under the finish, as described in the section on valves, page 376.

Glass aerosol containers can be coated or uncoated, but for safety reasons, dip-coating the exterior with a plastisol creates a preferred bottle that prevents glass fragments from scattering if it should be dropped. Such coatings also are used on some nonaerosol ware slated for use with chemical reagents and similar dangerous chemicals (see Chapter 9, Glassware).

The coating, a dispersion of fine particles of polyvinyl chloride (PVC) in a plasticizer, also can be compounded with stabilizers, fillers, modifiers, and colorants to add other decorative, functional, and safety features. In application, the compound is heated and the PVC swells and absorbs the liquid plasticizer until, after reaching a temperature above 300 F (148.9 C), the mixture coalesces into an homogeneous, cured coating. Three types of plastisols are available: smooth and glossy; matte and dry-textured; or smooth and autoclavable (for medical products). These coatings are recommended to have a minimum tensile strength of 2,000 psi (13.8 MPa) at 70 F (21 C).

Coated-glass aerosols pressurized with a flammable propellant can be shipped in interstate commerce if the overflow capacity does not exceed 4 fl oz (118 ml). Larger aerosols of this description must obtain an exemption from DOT. DOT also requires that glass aerosol containers be capable of withstanding pressures at least equal to 1.5 times the pressure of the contents at 130 F (54 C) without leakage or permanent deformation. While there are no other formal limitations for aerosols under 4 fl oz (118 ml) in capacity, it is recommended that uncoated glass aerosols containing a flammable propellant should not exceed 1.4 fl oz (41 ml) in overflow capacity. Aerosols containing a nonflammable propellant, not usual today, have less stringent recommendations.

Separated Containers

Environmental concerns about chlorofluorocarbon (CFC) propellants in the 1970s resulted in a number of innovations in pressure packaging, some of which also were rooted in the ability to handle products that reacted unfavorably to some propellants. One type is characterized by the fact that it uses air as the propellant and the containers are reusable. The universal feature of the other types is that the product and the propellant are separated from each other.

These special pressure packages are used for a wide variety of products ranging from insecticides to personal products, household items, and food spreads. When foods are the product, it is important to avoid ones that are fibrous in nature, which could clog valves.

The cans can be any type but most often are two-piece steel or aluminum. Pistons have been injection molded but also are thermoformed, a construction that is said to be more resilient and to conform better to dented can walls. Increasingly, all types of separated pressure packages are being made in multiple sizes.

A unique form of air-propelled reusable pressure package is injection molded of polypropylene (PP) with a dome that can be unscrewed to refill the container. The pressure is supplied by a removable, internally positioned pump. It is activated by an external knob and shaft, which can be locked to hold pressure in the container and also serves as the stand-up base of the package. The container is completed by a standard valve and nozzle but also may be equipped with a foaming nozzle. The unit is priced between $1.50 and $1.75 and can be sold empty or filled and then can be refilled from bottled product. The supplier is targeting such agricultural uses as sprays for greenhouses, nurseries, and garden centers.

Another version of an air-propelled sprayer locates the pump at the top of the container, which is made from high-density polyethylene (HDPE) or polyethylene terephthalate. An integral dip tube brings product to a conventional valve. A screw collar attaches the unit to the canister (Figure 11.4).

In a third type, a cup-like free-floating piston isolates the product in the upper portion of the container and the propellant in the lower part. The piston, initially made of PE, is now PP, nitrile, or a sophisticated multilayer material to reduce propellant permeation. When the standard aerosol valve is triggered, pressure from the propellant forces the piston upward to dispense the product. The packaging operation places the piston cup into the very bottom of the container before the end is sealed in place. Product is filled conventionally through the valve. Propellant is injected under the piston through a small hole in the concave bottom, which is then sealed with a small rubber plug (see Figure 11.5).

A second form of separated aerosol containers has a separate product bag or pouch inside a propellant-filled container. In use, the bag gradually collapses as the product is dispensed. Several different bag-in-can styles are now on the market. In one example, the bag is accordion-pleated and hermetically attached to a standard aerosol valve (see Figure 11.6). In another, a monolithic film or barrier laminate bag is introduced into the can with an extended top that is smoothly folded outward over the curled valve mounting hole in the can. Product is introduced into the bag, which is then sealed by crimping the valve in place. The propellant is introduced through a hole in the base of the can and surrounds the product bag. In the final step, the propellant filling hole is sealed with a rubber plug.

Still another pressure package has no propellant at all. The product is enclosed in a pleated, PET tube that is enclosed in a rubber sleeve. The tube is fastened to the neck of a thin-wall plastic container by the valve crimp. As product introduced through the valve fills the inner tube, the rubber sleeve balloons. When the valve is activated to dispense product, the sleeve contracts, maintaining pressure on the tube (see Figure 11.7).

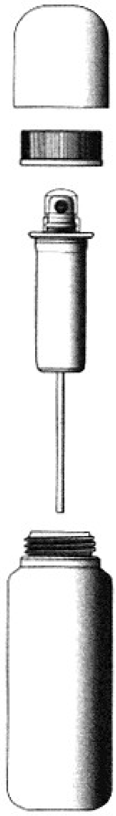

Figure 11.4.
Air-powered aerosol has a hand pump cap atop a conventional aerosol structure that is activated to build up internal pressure with seven to ten strokes. Three strokes after each dispensing keeps the system at proper pressure. The outer container, which can be of metal, glass, or plastic, is filled with product to a prescribed level before inserting the pumping/spraying mechanism, which is secured with a screw collar.
(Source: Airspray International Inc., Pompano Beach, Florida, used with permission.)

Figure 11.5.
Internal piston aerosol separates propellant, which is introduced through a small hole in the can base that is then plugged with a rubber stopper, and the product, which is loaded through the top before the valve is seated.
(Source: Advanced Monobloc Corp., Hermitage, Pennsylvania, used with permission.)

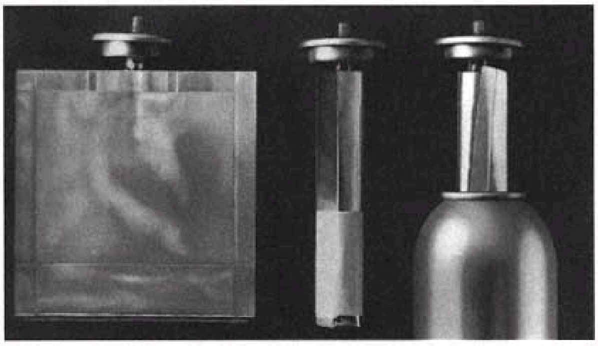

Figure 11.6.
Internal bag aerosol, called the Advanced Barrier System , consists of a laminated PP/foil/polyester bag that is sealed to a special PP housing on a standard aerosol valve. The bag is then rolled around the valve and secured for loading into the aerosol canister at speeds to 150 per minute. Product loading is through the valve. Gassing can be under the cup before crimping or through a hole in the can base, which is then plugged with a rubber stopper.
(Source: Advanced Monobloc Corp., Hermitage, Pennsylvania, used with permission.)

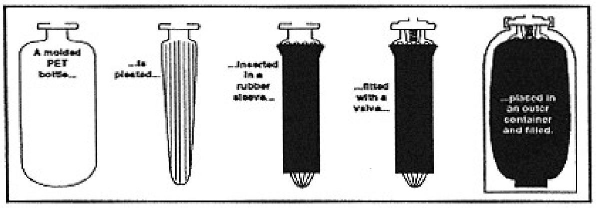

Figure 11.7.
Propellant-less aerosol contains a pleated polyester plastic liner that is enclosed in a rubber sleeve and inserted into a container. A conventional valve holds the assembly together. When product is pressure-filled through the valve, the rubber sleeve is distended to fill the container and contracts during product dispensing to supply the propelling power.
(Source: Exxel/Atmos, Inc., Somerset, New Jersey, used with permission.)

Valves and Other Components

There are many types of valves. Considering the number of different orifice sizes in the stem, body, and vapor taps, plus various dip-tube diameters and actuator combinations, the variations probably run into the thousands. Of the eighty or so manufacturers throughout the world, about twenty-five are considered major producers and only about five of these are in the United States.

The primary purpose of the valve is to control the flow of the product out of the container when it is needed, and to prevent any discharge when it is not wanted. A valve also has an important effect on the character of the product that is dispensed. For example, a foam product will come out as a foam, spray, or stream with different valves and actuators. Although it is not as significant a factor as the formulation, the valve is nevertheless one of the variables that contribute to the quality of the final product.

Essentially, the valve consists of a plastic stem which presses down on a rubber diaphragm contained in a hollow plastic body. When the valve is forced down, or in some cases, when it is tilted, it stretches the rubber away from an opening in the body so that the pressurized contents escape through the hole.

A metal cup is used to attach the valve to the container, an actuator button directs product dispensing, and a dip tube reaches down to the product at the bottom of the container (see Figure 11.8). With minor modifications from different manufacturers, they all work about the same way.

Orifice sizes in the body, stem, and actuator range from 0.010 to 0.080 in. (0.254 to 2.032 mm). There will be differences in the shapes of the mixing chambers, which may affect the spray pattern, but each valve manufacturer usually has several variations to offer. Foam valves are quite different from spray valves and different products require different orifice sizes and configurations (see Table 11.4 for valve orifice dimensions).

For food toppings, valves are usually of the tilt type, and designed to be used in the inverted position without a dip tube. Shave cream, however, is always used upright and includes a dip tube, which reaches to the bottom of the can. The actuator on a foam valve generally has a long stem and no restrictions so that it can act as an expansion chamber. The only orifice is the one at the valve seat, which is usually quite large.

Spray valves may have several orifices, with expansion chambers in between. The bottom of the valve body, known as the tailpiece, may be restricted to reduce the rate of discharge. The next orifice is in the valve stem, the third is in the actuator, and there may be a fourth if there is a vapor tap or an insert is added to the actuator. These orifices usually become progressively larger, for example, 0.016, 0.018, 0.020, and 0.022 in. (0.406, 0.457, 0.508, and 0.559 mm). The standard notation for specifying orifice sizes is to give the stem orifice first, then the body, followed by the vapor tap, if there is one, in this manner: 0.018   0.080   0.020.

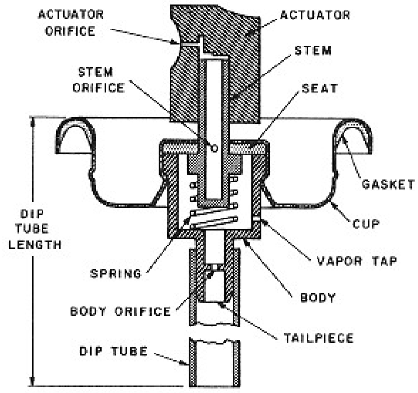

Figure 11.8.
Parts of a typical aerosol valve include the metal cup, which has a standard 1-in. (25.4-mm) opening in a metal container. The four orifices (body, stem, actuator, and valve tap) vary in size to suit different products. Other types of actuators can be used interchangeably.

TABLE 11.4. Typical Orifice Sizes for Different Products.

Product	Body Orifice	Vapor Tap	Stem Orifice	Actuator Orifice	Delivery Rate
Hair Spray	0.013		0.013	0.020RT	0.6
Hair Spray	0.062	0.013	0.013	0.018	0.8
Deodorant	0.018	0.018	0.018	0.015RT	0.7
Room Freshener	0.030		0.018	0.020	1.0
Room Freshener (water base)	Capillary	0.030	0.030	0.030	0.9
Oven Cleaner	0.062		0.030	0.018MBU	1.1
Insecticide	0.080	0.016	0.020	0.025MBU	1.8
Deicer	0.062		2 0.036	0.040	9.0

RT = reverse taper, MBU = mechanical breakup.

g/sec @ 70 F (21 C).

An actuator with an insert will probably have a swirl chamber. It is called a mechanical break-up actuator. The swirling causes the product to issue as a wide, hollow cone, breaking up into a fine mist as it spreads out. Without the mechanical break-up feature, the spray would come out as a narrow, solid cone, and in the case of a three-phase system, in which the product does not mix with the propellant, it might be a coarse spray containing many large droplets.

Delivery is mainly a function of the body orifice, product density, size of the vapor tap, and the number of stem orifices. The extra restriction of an actuator with a mechanical break-up chamber will somewhat reduce the delivery rate. However, lower pressures can be used, and the mechanical breakup feature has made it possible to put perfumes into uncoated glass containers.

The break-up chamber also is useful when the ratio of propellant to product is low. One other effect of the mechanical breakup is to reduce the chilling effect on the skin because of the soft, wide spray pattern. A vapor tap also has this effect by diluting the issuing gas with vapor from the headspace, which is at room temperature.

An oil-based insecticide spray that mixes readily with the propellant, on the other hand, would not need this extra breakup, and most of the particles would be under 30 m (0.0012 in.) in diameter just from the expansion of the propellant. Another variation in actuator orifices is the reverse-taper channel. The effect of this construction is to spread the spray over a wider angle.

A "vapor tap" hole in the side of a valve body, which allows a small amount of propellant to escape into the valve and mix with the product as it is dispensed, helps break spray into a fine mist and is particularly useful with water-based products in which the propellant and concentrate are immiscible. However, a good balance is required between the size of the vapor tap and the amount of container propellant. A spray that is intended to coat the surface rather than remain suspended in the air will need larger droplets, above 0.002 in. (51.3 μm) in diameter.

Powder aerosols work best with valves that have a high seating pressure with the seat close to the terminal orifice, especially if there is more than 10 percent powder in the formulation. A fine powder with a particle size under 200 mesh is preferred, and the propellant should have a specific gravity close to that of the powder, to minimize settling. High pressure and a low percentage of solids give the least trouble with clogged valves.

Metering valves deliver a predetermined amount and then automatically shut off. They do this with a double valve construction in which one valve closes when the other opens. The product that is in between is discharged by the pressure of the propellant mixed with the product. When the valve is released, the pressure in the container refills the chamber. This type of valve is suitable only for products that are miscible with the propellant, although there are some that use a steel ball in the dip tube as a check valve. These are partly successful with three-phase systems. Metering valves are available in different "shot" sizes, such as 50 mg, 100 mg, etc., up to 28.3 g (0.0018, 0.0035, and 1 oz), with a variation of about 10 percent, although some may be a little more accurate.

Pressure filling, in which the product is put into the container and the valve secured in place before the propellant is added, requires special designs in some cases. One valve, for example, has flats on the stem that provide openings for filling instead of going through the stem orifice. Low-swell rubber compounds have been developed, and noncracking dip tubing is available to minimize malfunctions.

Some valves are designed to work in any position. One type has a steel ball inside that drops away from a special orifice when the package is inverted. A mixing valve that combines two materials as they are dispensed has applications for hair coloring, toothpaste, and shave cream. At one time, co-dispensing valves for shave creams heated by chemical reaction were offered by all major valve manufacturers. Such valves allowed an oxidizing agent, such as potassium sulfite, to combine with a peroxide to generate the heat. A flexible plastic bag attached to the bottom of the valve contained the peroxide. This was surrounded by the shave cream, which contained the oxidizing agent along with the propellant. The proportions of shave cream to peroxide that went through the valve was about four to one.

An interesting development has been a self-contained pressure unit, which can be attached to the top of any type of container. In these units, a siphon tube passes down through the center or off to the side of the propellant container. Since the product section is not under pressure, it can be made of glass, plastic, or any other material. The spray pattern is limited to a wet type of spray, since the operation depends on venturi action to draw the liquid from the lower compartment.

Valves that are used with cans always have a 1 in. (25.4 mm) cup diameter, which is seated within the curl (can bead or rounded finish) and around which the valve cup is "crimped," (see Figure 11.9). But for glass containers and purse-size metal containers, the valves have a metal ferrule that must fit much smaller finish diameters of 13, 15, 18, 20 or 22 mm (0.51, 0.59, 0.71, 0.79 or 0.87 in.) (see Figure 11.10). The skirt length on any of these valves is between 0.285 and 0.325 in. (7.24 to 8.26 mm) to suit the particular container being used. It should be long enough to "clinch" well under the finish of such glass and some aluminum containers.

There are three types of aerosol gaskets: PE sleeve, cut gaskets, and laminates. Valve gaskets are made of either neoprene, Buna N, or Viton rubbers, depending on the formulation of the product. Neoprene is most often used with water-based systems. Buna is used for most DME-propelled products. Viton gaskets, which have the highest resistance to solvents, are used mostly

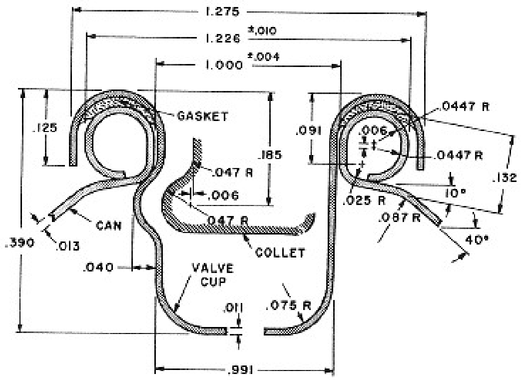

Figure 11.9.
A good seal between valve and container is important to prevent leakage. The critical dimensions of the valve cup and the container opening must be carefully maintained to ensure a tight closure.

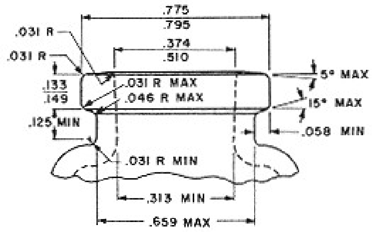

Figure 11.10.
Dimensions of a 20-mm (0.8-in.) biological, or No. 2710 finish, on a glass bottle are shown. Valves with metal ferrules to fit this opening are widely used for cosmetics and toiletries.

for the really tough products, such as insecticides and are only about 10 percent of the total gaskets employed.

Top pressure during crimping should be sufficient to compress the sleeve and cut gaskets to about 40 percent of their original thickness. Laminates are less resilient and only require sufficient pressure to compress 15 to 30 percent. A good way to check the compression is to grind away part of the ferrule on a sealed unit against a fine grinding wheel until the gasket is exposed.

A similar technique is also used to check the valve crimp. In this method, a motor-driven rotary abrasive disc is used to cut through the crimped area, either totally or halfway longitudinally. In the latter case, a second cut is used to remove a pie-shaped sample. This test and other procedures are detailed in the *CSMA Aerosol Guide* [4].

There is quite a difference in cost among the various standard valves, with prices for a simple valve without an actuator button running from about $45 to $74/1,000 in quantity. A simple and small button actuator will add $8 to $12/1,000. Metering valves and other special constructions command a premium price as high as $154/1,000.

Actuators

Actuators are made in different shapes for special purposes, such as cake decorating, vapor inhalants, and spot treatment of weeds. Other types of actuators include foam heads and spouts, upwardly directing sprays, mastitis and vaginal applicators, spreading combs, and mother-daughter transfer devices (for reloading a purse-size container from a master aerosol). In some cases, overcap and actuator are combined in such a way that the valve can be worked with the cap in place.

Overcaps

To protect the valve from accidental discharge and keep dust and dirt away from this mechanism, an overcap is usually applied to the aerosol container. It can be made to fit inside the chime on three-piece metal containers or over the chime with an inner cup that snaps over the valve cup. Caps also are available for necked-in cans, which give the package a completely straight-sided appearance. Sometimes the actuator and overcap are combined so the cap does not need to be removed, and product dispense through an opening in the side of the overcap. Other actuators are equipped with pilferproof devices that prevent discharge before purchase. Still others are created with special display shapes; such as a fireman's hat for a fire extinguisher, a dog's head for a canine shampoo, or a simulated swirl of whipped cream for a food topping.

Dip Tubes

Dip tubes are made from PE tubing and usually are cut to a precise length that reaches almost to the bottom of the container. With some products the dip tube tends to "grow," owing to absorption of solvents, and must be made shorter so that it does not seal off against the bottom of the container. Dip tubes are usually curved, simply because it is impossible to make them straight. To ensure that the maximum amount of the contents can be dispensed when the can is tilted forward, it is common practice to put a red dot on the rim of the valve cup in the direction that the dip tube curves. Then the actuator button can be oriented in the same direction as the red dot. In this position, the dip tube will not extend into the vapor phase even when the container is tipped nearly horizontal.

Propellants

There are three broad classes of aerosol propellants: hydrocarbons, compressed gases, and hydrofluorocarbons. Hydrocarbons used in volume today are propane, isobutane, normal butane, and dimethyl ether, which is included in this group because it relates more closely to the hydrocarbons than it does the other propellants. The hydrofluorocarbons are HFC-152a and HFC-134a. The compressed gases are carbon dioxide, nitrogen, and nitrous oxide. See Table 11.5 for the properties of these propellants.

Several factors are involved in the cost of propellants. The cost/lb is only one element in the total analysis (see Table 11.6). Density also is important in the calculations. For example, the density of hydrocarbons is only about one-half that of hydrofluorocarbons. The filling rate also should be taken into account. A product that can be rapidly UTC-filled will have a lower packing cost than one that has to be filled more slowly through the valve. Also, the cost of handling bulk propellants from the supplier and special safety provisions for explosive gases should be considered.

Hydrocarbons

About 90 percent of the aerosols produced in the United States are propelled solely by hydrocarbons. Isopentane and pentane propellants are used primarily in foam-forming aerosols, where the boiling of the propellant at skin temperature in the gel-type product produces the foam.

Hydrocarbon propellants, DME, and hydrofluorocarbons are liquids when confined in a spray container. They exert a pressure ranging from 17 to 110 psig (117 to 758 kPa) at room temperature. Many aerosols have pressures of around 40 psig, which varies slightly at different temperatures and also with the concentration of vapor pressure, percentage of propellant, and its pressure. But as long as there is any liquid remaining in the container, the pressure will remain relatively constant (see Figure 11.3). Hydrocarbon propellants are mixed with hydrofluorocarbons for some applications.

Elsewhere in this book, pressures are given in lb/in.^{2} (psi). But in dealing with aerosols, it is customary to specify "gauge pressure" (psig) or "absolute pressure" (psia). Absolute pressure is the pressure above zero pressure (a complete vacuum) and is, therefore, about 14.7 lb above gauge pressure at sea level. It is also constant, which is why it generally is used in scientific research work. Gauge pressure, as the name indicates, is the pressure shown by a gauge and is the pressure above atmospheric pressure, taken as zero and which varies with atmospheric conditions. The metric equivalent is the pascal (1 psig = 6,895 Pa).

The hydrocarbons are low in cost (see Table 11.6). Butane, isobutane, propane, and DME are used particularly with water-based products, but also are chosen for many solvent-based products. Hydrocarbons must be shaken to mix the propellant and the product. Extremely flammable, however, these gases should be handled with suitable precautions and label copy must conform to the requirements of the U.S. Consumer Product Safety Commission (CPSC), Washington, D.C.; the Environmental Protection Agency (EPA), Washington, D.C.; and the Federal Hazardous Substances Labeling Act, which is administered by DOT.

The flammability of any aerosol propellant is roughly proportional to the number of hydrogen atoms in the molecule, and hydrocarbons have the maximum (see Table 11.5 for hydrocarbon properties). However, the aerosol label statement of flammability is based on a flame extension test, not on the flammability of the propellant.

The hydrocarbons are identified by the letter A followed by a number which

TABLE 11.5 Properties of Aerosol Propellants.

Property	Units	Propane A-108	Isobutane A-31	n-butane A-17	Dimethyl ether DME	1, 1-Difluoroethane HFC-152a	1, 1, 1,2-Tetrafluoroethane HFC-134a	Carbon Doixide	Nitrogen	Nitrous Oxide
Formula		C^3H_8	C^4H_{10}	C_4H_{10}	H_3-O-CH_3	CH_3CHF_2	CH_2CHF_3	CO_2	N_2	N_2O
Molecular Weight		44.1	58.1	58.1	46.1	66.1	102.0	44	28	44
Boiling Point	Deg. F	-43.7	10.9	58.1	-12.7	-13.0	-15.2	-109	-320	-127
	Deg. C	-42.1	-11.7	-0.5	-24.8	-25.0	-26.2	-78	-196	-88
Vapor Pressure	psig.	108	31	17	63	63	71	837	477	720
Liquid Density	g/cc	0.508	0.563	0.583	0.66	0.91	1.222			
	lb/gal	4.234	4.599	4.864	5.508	7.594	10.195			
Specific Gravity (water @ STP=1)		0.508	0.563	0.583	0.66	0.91	1.222 3.52			
Vapor Density (air @ 70 F=1)		1.55	2.05	2.07	1.59	2.28	3.52			
Lower Explosive Limit	Percent	2.2	1.8	1.9	3.9	3.3	NA			
Upper Explosive Limit	Percent	9.5	8.4	8.5	16.9	18.0	NA			

At critical temp. of -233 F (-147 C).

indicates the pressure. Thus, n-butane is designated propellant A-17 because it has a pressure of 17 psig (117 kPa) at 70 F (21 C). Isobutane is called propellant A-31, and propane is known as propellant A-108 (see Table 11.5). The pressures given may not agree with the textbook values, because aerosol-grade gases are not absolutely pure but contain small amounts of other gases. In fact, mixing is a common technique to provide pressures in between those of the individual gases (see Figure 11.11). Commonly used blends are A-46 and A-70. Since the density of most hydrocarbons is about one-half that of the hydrofluorocarbons and cost less, they offer a great cost advantage.

In a three-phase system, the lighter-than-water hydrocarbons will float on top of the product, eliminating dip tube length problems associated with heavier propellants. Since hydrofluorocarbons sink, a fluorocarbon/hydrocarbon blend makes it is possible to match the density of the product, thereby making it easier for water-based products to mix when the container is shaken. However, the possibility of hydrolysis of hydrogenated hydrocarbons precludes their use in most aqueous systems.

Various combinations of propellants are used for special purposes, and some of these get very complicated. One formulation for hair spray, for example, has water and alcohol in amounts sufficient to dissolve a limited amount of propellant, leaving the excess as a separate top layer. Since pure hydrocarbon would be too flammable, a hydrocarbon and fluorocarbon mixture is used, with enough hydrocarbon to cause the excess to float above the mixture of concentrate and the dissolved propellant.

It should be noted that temperature has a significant effect on aerosol pressure and some aerosols will not work effectively outdoors in the wintertime. This is most true of the hydrofluorocarbon and hydrocarbon propellants and is least noticeable in compressed gases (see Figure 11.12).

TABLE 11.6. Propellant Costs.

Propellant	$/lb, Truckload Delivered
Carbon Dioxide	0.040
Nitrogen	0.083
Nitrous Oxide	1.000
Propane	0.263
Isobutane	0.263
Normal Butane	0.245
Dimethyl Ether	0.471
HFC-152a	1.901
HFC-134a	2.051

Cylinder quantities.

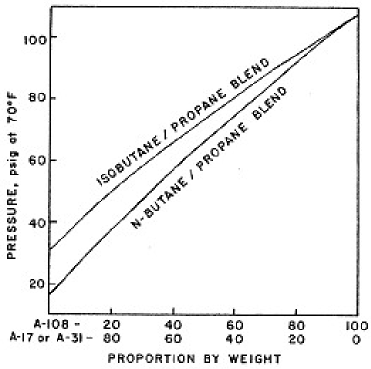

Figure 11.11.
Various proportions of propellants in a mixture will provide different pressures. Thus, any desired pressure over a wide range can be obtained by choosing the right amount of each component.

DME and the hydrocarbons are volatile organic compounds (VOCs) and, therefore, could be restricted under some federal regulations and, particularly, under the stringent regulations now in force in California and some other states.

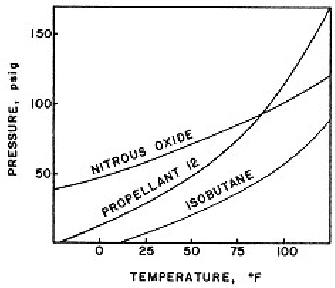

Figure 11.12.
An increase in temperature will have a marked effect on the pressure within an aerosol container. This is most significant with the hydrofluorocarbons and least noticeable with the compressed gases.

Compressed Gases

The second class of propellants consists of nitrogen, carbon dioxide, and nitrous oxide, which do not liquify, but remain as a gas or dissolve in the product. They are loaded to a pressure of about 100 psig (690 kPa), which drops at a steady rate as product is dispensed and the headspace increases (see Figure 11.3). As the product dispenses and head pressure drops, some dissolved gas is released into the headspace, partially compensating for the drop in pressure.

Nitrous oxide and carbon dioxide are partially (3 to 5 percent) soluble in many products, and to that extent, take on some of the properties of the liquefied propellants. The two gases sometimes are combined for food products because the sweet taste of the nitrous oxide offsets the acidic taste of the carbon dioxide.

Carbon dioxide generally is not specified for aqueous products because of undesirable chemical reactions. For food products, nitrogen, nitrous oxide, and carbon dioxide, are most generally used, and blends of two or more are sometimes also employed. Butane and propane affect taste, as do most of the hydrofluorocarbons.

Nitrogen is nearly insoluble (about 1.5 percent in water and 14 percent in alcohol) and, thus, helps produce a solid stream of such products as pastes and liquids. It often is used at a starting pressure of up to 150 psig (1,034 kPa) at 70 F (21 C). The amount of pressure left when the product is all used up will depend on the amount of headspace at the start. With a 25 percent headspace, for example, an initial pressure of 100 psig (690 kPa) will drop to 25 psig (172 kPa) when the contents are depleted. Also, with each 10 F (5.6 C) rise in temperature, pressure increases about 2 psig (14 kPa). Liquid hydrocarbon or fluorocarbon propellants require about 10 to 15 percent headspace for gas expansion. In the case of nitrogen, the government specifies only that there must be headspace remaining when the temperature of the contents is raised to 130 F (54.4 C) in a hot-water bath test.

Fluorocarbons

CFCs were discovered in the 1880s, but did not achieve any economic significance until they began to be used as refrigerants in place of ammonia and sulfur dioxide in the 1920s. Subsequently, they also were applied as aerosol propellants and as foaming agents for the creation of plastic cushioning and insulation. The vapors are heavier than air and have a low toxicity, the most common ones being safe to breathe at a concentration of 1,000 ppm.

However, in 1974 an article in *Nature* magazine by Dr. Mario J. Molina and Dr. F. Sherwood Rowland set off a chain of events that has resulted in great changes for CFCs. The University of California professors postulated that CFC aerosol propellants rising in the atmosphere could release sufficient chlorine atoms to reduce the ozone layer by as much as 15 percent by the year 2000. Since ozone forms a protective shield against actinic rays from the sun, any reduction in this shield could cause an increase in skin cancer as well as affect weather, food crops, and other earthly matters.

In support of this thesis, Dr. Julius London and Dr. Jean Kelley reported in *Science* magazine that during a ten-year period of great CFC production there had been a 7.5 percent increase in the amount of ozone in the northern hemisphere. The Rand Corporation, Santa Monica, California, was commissioned by the EPA to make a further study, and later the National Academy of Sciences, Washington, D.C., declared that there might be a serious problem. As a result, EPA, FDA, and the CPSC acted jointly to ban use of "fully halogenated chlorofluorocarbons" except for a few "essential" and "medical" applications [5].

Amendments to the Clean Air Act in 1990 tightened the regulation by prohibiting the simple discharge of CFCs (a Class 1 substance) or their ingredient use in most commercial or consumer products. In 1993 a further tightening essentially ended the use of CFCs in aerosols and other products, and in 1994 the same bans were applied to hydrochlorofluorocarbons (HCFCs), a Class 2 substance. (See Chapter 21, Packaging and the Environment for more details on EPA rules.)

In the meantime, however, several flammable and nonflammable hydrofluorocarbons (HFCs) with less environmental impact have been created for use in aerosols and the other applications. HFC-152a and HFC-134a now are produced in sufficient quantities to service the aerosol industry (see Table 11.5 for properties).

The numerical system used in Table 11.5 to designate the different fluorocarbon propellants is based on molecular structure. The first digit indicates the number of carbon atoms minus 1. If this is zero (one carbon atom), it is dropped. The second digit shows the number of hydrogen atoms plus 1, and the third digit gives the number of fluorine atoms. If the compound is an isomer, a compound containing the same composition as another but differing in structure, a letter is added to the numbers.

None of the aerosol HFCs are regulated under the U.S. Clean Air Act of 1990 since they have a zero potential for ozone depletion. HFC-152a and HFC-134a also are not VOCs, but HFC-134a has a rather long atmospheric life and a much greater global warming potential. Thus, its use is not as desirable as DME and HFC-152a, which both have short atmospheric life spans. HFC-134a is used where its nonflammability is important to an aerosol product or as a blend with DME and HFC-152a to greatly reduce or completely eliminate their flammability.

The HFCs are miscible with each other, with hydrocarbon propellants, and with the solvents generally used in aerosol products, such as alcohol. Therefore, they can be blended with each other or with the hydrocarbons to give a range of desired pressures. They have vapor pressures in the medium to high ranges. All three have low toxicities. As with previous propellants, the new ones have a slight odor.

Needless to say, research by the aerosol industry continues to find even better propellants than the current improvements.

Diluents

A number of compounds are used with propellants to improve solubility or reduce pressure. Among these are glycol ethers, mineral oil, and petroleum distillates.

Gas Laws

Certain principles of physics cover compressed gases, and the following may help in understanding the behavior of aerosol propellants. Strictly speaking, these statements will apply only to a perfect gas at low pressure, and real gases will deviate slightly from these rules.

First is Boyle's Law: The pressure of a gas varies as the inverse of volume and conversely, the volume varies as the inverse of the pressure, provided that the weight and temperature are constant:

$$\frac{P_{\text{initial}}}{P_{\text{final}}} = \frac{V_{\text{final}}}{V_{\text{initial}}}$$

Note: A mole of gas occupies 22.4 L at 32 F (0 C) and 14.7 psia (101 kPa). If 1 ft^3 of gas at a barometric pressure of 29.92 in. Hg (14.7 psia, 101 kPa) is compressed with a pressure of two atmospheres or 59.84 in. Hg (29.4 psia, 203 kPa), the volume will be the inverse of the change in pressure, or 0.5 ft^3.

Next is Charles' Law: The volume of a gas is directly proportional to the absolute temperature (F + 459.2 or C + 237). For example, 1 ft^3 of gas taken at 70 F (21.1 C) and heated to 90 F (32.2 C) will increase to:

$$\frac{V_{\text{final}}}{1\ \text{ft}^3} = \frac{90 + 459.2}{70 + 459.2} = 1.04\ \text{ft}^3\ (0.03\ \text{m}^3)$$

Note: If more than one gas law is involved, you should figure them successively, in any sequence.

Next is Avogadro's Law: Equal volumes of all gases at the same temperature and pressure contain the same number of molecules. One molecular weight (a mole) of a gas will occupy 22.4 L at 32 F (0 C) and 1 atmosphere of pressure. To find the rate of expansion, first find the volume of 1 mole of gas when it is in the liquid state:

$$\text{Volume} = \frac{\text{molecular weight}}{\text{density}}$$

For propellant HFC-152a, density of the liquid is 0.91 and the molecular weight is 66.1. Therefore:

$$\text{Volume} = \frac{66.1}{0.91} = 72.6\ \text{cm}^3 = 0.0726\ \text{L}$$

The volume of propellant HFC-152a in the gaseous state, 22.4 L, is thus 308 times that in the liquid state, 0.0726 L.

Finally, there is Raoult's Law: The vapor pressure of each component in a mixture of gases is proportional to its mole fraction. To review the definition of a mole, the atomic weight of hydrogen is 1 and that of oxygen is 16. The sum of atomic weights in a molecule of H_2O is 18. A gram-molecular weight, usually shortened to mole, is the same thing expressed in grams; Thus, a mole is 18 g of water.

An example of an aerosol propellant mixture and the pressure it can exert in application is a mixture of HFC-152a (flammable) with HFC-134a (nonflammable) to create a mix that is nonflammable. It is suggested that no more than 12 percent by weight of HFC-152a be included in such a blend. The mixture is then HFC-152a/HFC-134a (12:60). The molecular weight of HFC-152a is 66.1, of HFC-134a, 102. Therefore:

$$\frac{12\%}{66.1} = 0.182\ \text{mole} \qquad \frac{88\%}{102} = 0.863\ \text{mole}$$

To find mole fractions, divide each of the above by the total:

$$\frac{182}{1045} = 0.174 \qquad \frac{863}{1045} = 0.826$$

Multiply mole fractions by absolute pressure of each pure gas, as in this example:

$$\begin{aligned}
\text{HFC-152a vapor pressure @ 70°F} &= 63\ \text{psig} + 14.7 = 77.7\ \text{psia}\\
\text{HFC-134a vapor pressure @ 70°F} &= 71\ \text{psig} + 14.7 = 85.7\ \text{psia}\\
0.174 \times 77.7 &= 13.52\\
0.826 \times 85.7 &= 70.79\\
\text{Total pressure} &= 84.31\ \text{psia (581 kPa)}
\end{aligned}$$

The pressure in aerosols must be actually tested from time to time to insure performance levels. There are two methods. One is to puncture the base of an inverted aerosol with a pressure-gauge assembly having a sharpened spike for penetration. The second is to measure the internal pressure through the aerosol valve stem.

Labels

The three-piece metal can is the most widely used container and lithography is commonly used for its decoration. However, it suffers from one aesthetic drawback. Because the side seam cannot easily be covered with lithography, the bare metal must be left exposed. However, both paper and shrink-film labels can be used to overcome this objection and offer a wide choice of embossing and printing techniques (see Chapter 12, Labeling and Decorating).

Filling Processes

The earliest method of filling nonaqueous products was cold filling. It is no longer used because UTC filling is much more efficient. In this method, after the product is introduced, the valve is positioned loosely in place, and a filling nozzle that covers the valve and seals off against the can first pulls a vacuum, then flows the propellant around the suspended valve, which is then crimped into place. This fast process is capable of filling more than 200 aerosols per minute.

Some products are pressure-filled with the product introduced at room temperature. The valve is vacuum-crimped into place before the propellant is added. A small amount of propellant may be put in to purge the container of any remaining air before the valve is fastened. Hydrofluorocarbon propellants are almost five times as heavy as air and will displace it from the bottom up. If the trapped air were not removed by purging or vacuum-crimping, it might increase the pressure in the finished package by as much as 15 or 20 psig (103 or 138 kPa). The bulk of the propellant is then forced in through the valve stem.

Originally, it was necessary to use a rotary gasser/shaker to fill cans with a compressed gas, and that method still is used to some extent. Then came the "saturation tower" and the "undercap filling" system. Today the most common filling method is "impact gassing." This is similar to the method used with liquefied gas propellants. After the product is put into the container, a measured amount of gas is introduced at a pressure of about

600 psig (4,137 kPa). The displaced air is allowed to escape, and the pressure in the can rises to about 120 psig (827 kPa). There is considerable turbulence within the can during the filling operation, and as the gas is dissolved into the concentrate, the pressure gradually drops to the final saturation pressure. Sometimes compressed gases can be filled using a pressure filling method, but this is limited to products that use a very small-diameter stem and body orifice. There is also the danger of blowing off the dip tube.

Glass containers should be pressure-tested at 150 psig (1,034 kPa) before filling. A special “puck” or cup made of plastic is used to hold each glass or aluminum container, particularly those with an unstable shape, while it is being handled on the production line. Tinplate cans of the standard 202, 207.5, 211 and 300 diameters will fit the usual feeding mechanisms and do not require pucks. However, each size does require specific change parts.

Other operations usually performed on an aerosol filling line include container cleaning, code marking, labeling, inspection, weighing, and valve testing.

Specifications

The valve should be specified in sufficient detail and with tolerances to cover all orifices, type of gasket material, and stem and body material(s). Other data are dip tube dimensions and material, actuator type and orifice sizes, and valve cup coatings. Details of the container include size (diameter and height), side and base weights, nonspecification or specification (2P, 2Q) requirements, coatings inside and outside, and the kind of decoration with number of colors and coatings, including bottom and top pieces.

Specifications for the overcap should indicate the type of material and its fit (inside or outside the chime, over a necked-in body, or over the breast or the valve cup). Decoration details also should be specified.

Recommendations and specifications for the complex dimensions of aerosol containers and components are published by the Chemical Specialty Manufacturers Association (CSMA), Washington, D.C., and by Committee D10 ofASTM (the American Society for Testing and Materials), West Conshohocken, Pennsylvania.

Testing

Before a new product is released to the trade, it should be thoroughly tested. Guidelines for construction and testing of aerosols are contained in the *CSMA Aerosol Guide.* Test methods should be as realistic as possible. That is, the container should be exhausted in short bursts, with an interval between successive bursts, not all at once. Storage conditions should be at room temperature, although quicker results will be derived at elevated temperatures. Some laboratories consider 90 days at 105 F (40.6 C) equivalent to 1 year at room temperature. But it should be emphasized that accelerated tests do not always correlate with results under normal conditions. Things to look for in stability tests are settling out of solid particles, degradation of perfume, crystal formation, lumping together of particles, corrosion, and leakage.

Control testing of component parts as well as the filled units from the production line should include visual examination of materials and coatings. Orifices can be checked with drills of the right size or by air-flow devices.

A spray pattern will show up on colored paper when the container is held a prescribed distance away. This should be tested with each new batch of containers from the production line. The particle size may be checked by various imaging systems. However, product testing frequently is performed by specialized laboratories, which can confirm that the product performs as specified.

A method for determining the degree of enamel coverage on the inside is to fill the container with a 5 percent solution of sodium chloride. An electrode is placed in the solution, and another against the outside of the metal can. A 5-V DC potential is placed across the electrodes with the positive side in the solution. If the flow of current, measured on a milliammeter, is more than 55 mA after 5 sec, the coverage is inadequate.

In order to find the location of the voids in the enamel, a mixture of a concentrated solution of copper sulfate and a few drops of sulfuric acid will plate out the copper wherever it contacts bare metal. Examination under a strong glass will then clearly show the exposed metal. The most vulnerable spots are in the fillet area of the seam, particularly at each end. For aluminum containers, a 1 percent solution of copper sulfate with 0.05 percent acetic acid and 0.005 percent sodium dioctylsulfosuccinate to remove grease, is used with a 5-V DC to measure the amount of discontinuity and to stain the bare areas. A reading is made after 5 sec, and the current is reversed to clear away the hydrogen bubbles, which would increase resistance to the flow of current.

When a new formula is being developed, the degree of flammability should be determined, and the regulations and tests for flammability should be clearly understood. A flammable compressed gas is defined by DOT as one "in which a mixture (by volume) of 13 percent or less with air forms a flammable mixture," 49 CFR Transportation, Part 173.306 (1); or (2), using the Bureau of Explosives Flame Projection Apparatus, the flame projects more than 18 in. (45.7 cm) beyond the ignition source in the test.

Aerosols that are exempt from DOT regulations are: (1) containers with not more than 4-fl-oz (118.29 ml) capacity; (2) aerosols of not more than 1-qt (946.35 ml) capacity charged with nonliquefied, nonflammable gas; (3) aerosols of up to 27.7-fl-oz (819-ml) fill in a regular can, if the pressure does not exceed 140 psig (965 kPa) at 130 F (54 C); (4) a DOT-2P can at 140 to 160 psig (965 to 1,103 kPa); (5) a DOT-2Q can at 160 to 180 psig (1,103 to 1,241 kPa). Note that containers between 19.3- and 27.7-fl-oz (571- and 819-ml) capacity require special markings on the shipping cases. Products regulated by EPA, FDA, or CPSC must be tested and labeled in accordance with their flammability requirements.

To test valves on coated glass bottles to see whether clinching is tight enough, a torque tester can be used. With a 20-mm (0.8 in.) size it should take between 10 and 18 lb.-in. (1.13 and 2.03 Newton-meters) to rotate the valve on the bottle. Although this is not an accurate test, strictly speaking, it offers a quick, easy method to check for proper torque at the production line.

A method of measuring this type of leakage on the production line consists of inverting a calibrated column of water over the valve. Bubbles will accumulate at the top of the column over a period of time, and this can be used to determine the rate of loss.

Pumps and Sprayers

There have been mechanical dispensers for various liquids for about 50 years and during this period four basic types have developed: fragrance pumps, fine-mist sprayers, trigger sprayers, and lotion pumps.

History

Prior to the 1970s, most fragrances were packaged in aerosol glass containers and mechanical finger pumps were primarily atomizers that were shipped separate from the bottles. Then, environmentalists became concerned about the effect that CFC propellants were said to have on the environment and work on development of finger-pump technology increased to create dispensing functions that were similar to the fine sprays, streams, and foams achieved with aerosols.

There has been steady development toward these objectives and a consequent growth in the use of finger pump dispensers for a wide variety of products, not only as an alternative to aerosols, but as a different approach to convenience that would access more shelf space in marketing.

Principles of Operation

Although there are four general classifications for mechanical pump dispensers and their many variations, the basic function and principles of operation for all pump dispensers are very similar.

In the 1970s, the precompression pump was introduced. It contains a central accumulator that holds product for dispensing. A piston pressurizes product in the accumulator, which has a passageway to the dispensing point, insuring fine atomization of the product regardless of the velocity of the pump stroke. Early pumps tended to dribble or stream if activated slowly.

Depressing the pump head moves the piston down into the accumulator, compressing the air in the chamber and lifting the top valve to allow air to exit the system (see Figure 11.13). As the head and piston return to their original position, a vacuum is created in the accumulator, closing the top valve and pulling product up the dip tube. Once product fills the chamber, the continued opening and closing of the valves under compression and vacuum pushes it through the system, drawing it up into the pump and then displacing it out through the head.

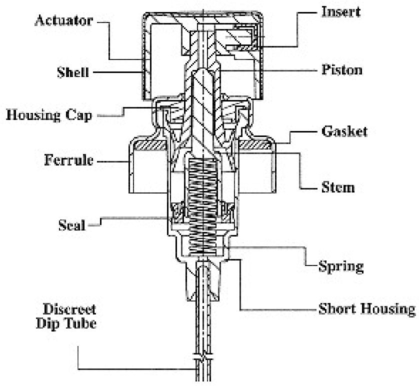

Figure 11.13.
With the development of precompression technology, which enabled a more constant spray, fragrances started converting from glass aerosols to pumps. Current developments in these designs include a more compact pump structure and container.
(Source: Emson Inc., Bridgeport, Connecticut, used with permission.)

Selection Criteria

The first products to benefit from the continuous dispensing feature of the precompression technology were fragrances. As other sophisticated needs developed, modifications of the basic components and actions described above have been created. As an example, fine-mist dispensers have adopted precompression technology that permits continuous spraying of the product, leading to uses in hair sprays, suntan lotions, topical antiseptics—anything that needs a fine spray and a dosage of about 180 l (see Figure 11.14).

Trigger sprayers often dispense large volumes of product and are equipped with an extended trigger, a lever that gives a mechanical advantage and prevents operator fatigue. There are also foaming devices and nozzles, which can be adjusted for the size or quantity of droplet desired. These

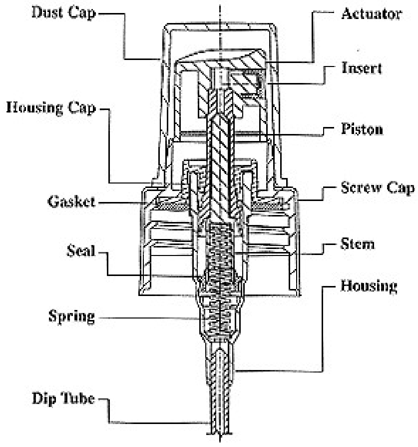

Figure 11.14.
Fine-mist sprayers were introduced in the early 1960s, primarily for room fresheners and other household products. Dosages per pumping run about 180 l. Adoption of precompression technology for more even dispensing then enabled these pumps to enter the field of personal hair-care products as well. (Source: Emson Inc., Bridgeport, Connecticut, used with permission.)

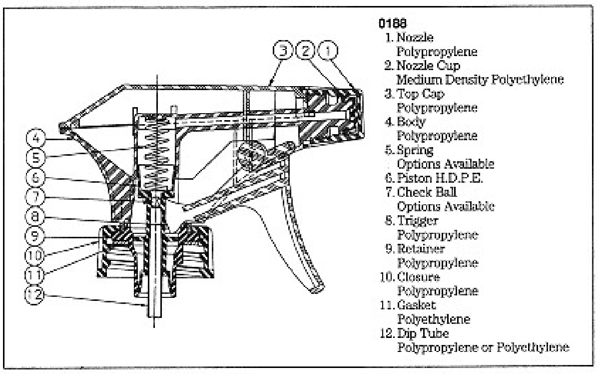

Figure 11.15.
Trigger pumps were introduced to dispense large volumes of cleaning compounds and sanitizers in institutional applications. To handle the larger volumes of product with less fatigue, the pump action was embodied in an extended and pivoted trigger. Dispensing is primed with three to five strokes and delivery is approximately 0.8 cc (0.03 fl oz). (Source: Owens-Brockway Closure and Specialty Products, Toledo, Ohio, used with permission.)

sprayers deliver large dosages covering a broad area and are ideal for household cleaners, sanitizers, and the like (see Figure 11.15).

Lotion pumps are an outgrowth of early pump sprayers that dispensed product as the pump head was pushed down (noncompression technology). They are fitted with an extended dispenser on the pump that smoothly delivers creams and lotions. The early pumps could not be shipped on the container, but the development of a lock-down version in the 1950s enabled a complete unit to be shipped intact and led to the popularization of this mechanical product dispenser in the personal-product fields of liquid soaps, shampoos, and moisturizers, as well as such food products as ketchups and mustards sized for fast-food outlets (see Figure 11.16).

The cost of pump and spray closures varies considerably depending on the task to be performed. A simple button pump for fragrances, fine mists, or lotions is priced about 20 cents. A trigger type will average about 35 cents, but all can also cost more depending on construction and intended usage.

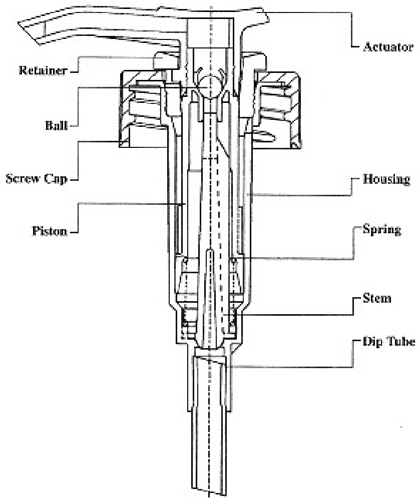

Figure 11.16.
Lotion pumps using noncompression technology, were among the earliest pumps and had to be shipped with the pump fitments packed separately. Invention of a lock-down design that prevented leakage enabled the package to be shipped with the pump in place and broadened its applications to household products and liquid food condiments.
(Source: Emson Inc., Bridgeport, Connecticut, used with permission.)

References

1. Anon. 1997. "Annual Survey," report by the Chemical Specialties Manufacturers Association, Washington, D.C.

2. Ibid.

3. Ibid.

4. Anon. 1996. *CSMA Aerosol Guide.* Washington, D.C.: Chemical Specialties Manufacturers Association, J-11.

5. EPA. 1996. Title 40 of the *Code of Federal Regulations* (CFR), 762.58; FDA. 1996. 21 CFR 2.125 e.

Chapter 12— Labeling and Decorating

Introduction

There are a number of reasons for using labels on packages. Some are made necessary by law or by logic; others are optional with the packager. In the first category, there are laws that demand that the product quantity, active ingredients, and the manufacturer's name be clearly displayed (see Figure 12.1). In some cases, special warnings must be imprinted if the contents may be hazardous to the user.

Among the optional uses of labeling are slogans and claims, which help promote the sale of the product, trade names, and descriptive phrases, instructions for use, cross advertising of other products, and many other applications of design and text to enhance the value of the package as a selling tool.

The choice of color and typography in labeling often plays an important role in the acceptance, use, and customer response, as well as the cooperation of the dealer. It can even be said that the success or failure of a packaged product can be attributed to the manner and style in which it is identified. The least costly item in a package is, thus, a most important factor at the point of sale (see Chapter 1, Elements of Packaging, page 18 for more on package design).

History

The word *label* has been used for many things down through the ages. In heraldry, it was a band across the upper part of a shield to indicate the eldest son of the family, and in clothing it usually referred to a ribbon or streamer

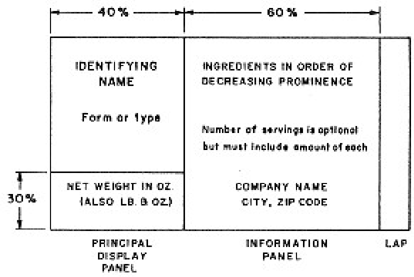

Figure 12.1.
The Fair Packaging and Labeling Act (21 CFR Part 101) requires the principal display panel of a cylindrical package to be 40 percent of the circumference (§101.1). A statement of identity in bold type and the form, if there is more than one, must be on the principal display panel (§101.3). The quantity statement must be in the lower 30 percent of the main panel. Ingredients must be listed in descending order of predominance on either the principal display or information panels (§1.12). The place of business must be conspicuously specified by the actual corporate name, city, state, and zip code, but not necessarily on the main panel.

attached to a head covering. Legal papers had a strip of fabric attached to carry a seal, which was called a label.

The labeling and marking of goods has a long history also, and the use of marks to indicate the source of a particular item can be traced back many centuries before Christ. Roman apothecaries are known to have dispensed an herb called Lycium in small jars bearing the name of the drug and the seller's name. Wines were usually sold in marked jars and bottles until clear glass replaced the dark-colored bottles that were used up to the end of the seventeenth century.

It then became customary to have the labels hanging loose from the bottle, held by a fine chain around the neck. Sometimes made of silver or ivory, these markers have become collector's items. Reproductions are sometimes seen on modern decanters for alcoholic beverages.

The descriptive type of labeling used today, on the other hand, has had a relatively short history. There are several reasons for this. For one thing, manufacturers and dealers of old were so familiar with the limited kinds of goods then available that they did not require tags to differentiate one from another. Besides, literacy was restricted to the wealthy, and all communication was on a person-to-person basis. As the variety of goods increased and education became available to the working classes, it became expedient to identify things with printed legends. A group of druggists in London, for example, adopted a set of regulations in 1819 for marking poisons, one of which read:

> *That on every wrapper or vessel containing any drug or preparation likely to produce serious mischief, if improperly used, the name of the article be affixed in a legible form, and as many persons can read print who cannot read writing, they would recommend that printed labels be used where possible, in preference to written ones.*

In 1888, however, an English novelist wrote, "Poison that is bought at a drug store *usually* has a label on the bottle," which would indicate that the regulation was not rigidly applied.

The promotional value of a label was not recognized or utilized to any degree until the beginning of the nineteenth century. It was about 1793 that Guinness started using the Irish harp symbol on its ale and stout to help the sales of its Dublin brewery. At about the same time, French wineries began to print labels containing elaborate scenes for their cordials and brandies. Similar designs also were used on matchboxes, bolts of cloth, food products, and medicines. Even today, such artwork appears on many cigar boxes.

Growth of labeling has been slow and steady. Now, however, with increased requirements from both consumers and retailers for product information, this packaging component is in great demand despite the rapid growth, as well, of direct decorating methods for many types of containers.

The most common of the new labels contain bar codes that now define a majority of products and can be scanned by electronic or optical devices to inform shippers and retailers alike of what a package contains and its price. Mandated for foods is the relatively new nutrition label (see Figure 12.2) and the Safe Handling regs (see Figure 12.3). The nutrition label defines the dietary constituents of the product and their amounts and the percentages of daily nutritional needs that they serve. Medical products, of course, have long been required to carry product names, lot numbers, and expiration dates.

Among the specially mandated labels are those for hazardous materials and hazardous waste. These products fall under the jurisdiction of the U.S. Department of Transportation, Washington, D.C., and the federal Environmental Protection Agency, Washington, D.C., respectively. The labels contain dedicated symbols and wordage that identify the product, its hazards, the types of containers in which it can be shipped, and the amounts permitted in various types of transport. Compliance with these somewhat complex regulations in both U.S. and foreign shipments requires special study (see Chapter 20, Laws and Regulations for more on labeling laws).

The majority of labels worldwide are plain paper adhered with wet glues. However, in the United States, rollstock pressure-sensitive (P-S), or what of-

Nutrition Facts

Serving Size 1 cup (228g)
Servings Per Container 2

Amount Per Serving

Calories 260 Calories from Fat 120

	% Daily Value*
Total Fat 13g	**20%**
Saturated Fat 5g	**25%**
Cholesterol 30mg	**10%**
Sodium 660mg	**28%**
Total Carbohydrate 31g	**10%**
Dietary Fiber 0g	**0%**
Sugars 5g	
Protein 5g	

Vitamin A 4% • Vitamin C 2%
Calcium 15% • Iron 4%

* Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

Figure 12.2.
Nutritional information in accordance with the Nutritional Labeling Education Act (21 CFR Part 101.9) shall be provided in the above specified format on a label for all packaged food products.

Figure 12.3.
Certain meat and poultry products must carry safe handling instructions to help consumers avoid foodborne diseases caused by pathogens like E. coli.

ten are termed "self-adhesive" labels are currently showing growth rates of 10 to 20 percent per year in many markets. Use of print-on-demand labels also is expanding at above-average rates for both product and transport containers. Other growth areas include stretch, shrink, heat-transfer, and inmold labeling.

Label Materials

Labels are available in both cut and rollstock forms and generally are made from paper, foil, film, or a laminate structure. For special applications, they also can be made from paperboard, fabrics, synthetic substrates, and even metals.

Paper

Most labels are printed on paper, the most economical material for large or small orders. They are generally produced by silk screen, letterpress, offset, flexographic, or gravure printing, but can be embossed and hot-stamped as well.

Paper labels can be low in cost or very luxurious in top-grade coated stocks. For luxury items, metallized papers, films, and embossed foils with silk-screen printing provide elegant packages at a higher price, of course. Simple paper labels will cost less than a cent each, while direct container printing is likely to cost more.

Paper labels can be die- or guillotine-cut. The first method provides accurate dimensions and freedom of design, such as rounded corners. It is higher in cost, however, since the labels must be cut one stack or "lift" at a time. In die cutting, a cast steel cutting die, of the proper shape and about 2 in. (5.08 cm) high, is placed in position on a stack of printed sheets. A die press forces the die down through the stack. The die is lifted out by hand and the labels are pushed through the die and accumulated on a nearby table. The die is then hand-placed on the next position to be cut, and the press is actuated to force it down once again. With foil labels, the die "cups" the edge and work-hardens the foil at that point, adding stiffness to the labels.

The majority of labels are guillotine-cut. That is, a stack of printed sheets is placed against an adjustable gauge plate and clamped in position (see Figure 12.4). A shear knife is brought down through the sheets, cutting off strips of labels. After cutting the sheets in one direction, the gauge plate is moved the proper distance from the knife and the lift is turned 90 degrees so strips can be cut into stacks of single labels.

Some variations in size will occur with guillotine cutting, depending upon the skill of the operator, but the labels should not be more than 1/64 in. (0.4 mm) from the specified size if the work is carefully done and the equipment is in good shape. The design of the labels is limited to straight parallel edges with this method, and the corners are always square and sharp, although it is possible to do some corner cutting in a subsequent operation if desired.

The direction of the grain in paper labels is usually very critical to the op-

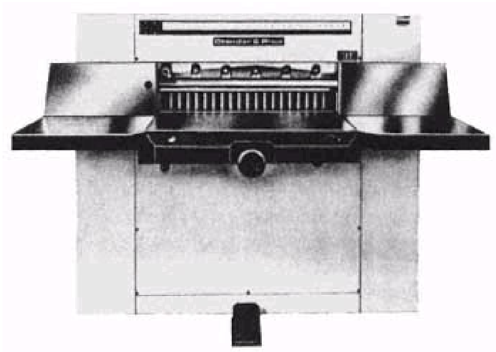

Figure 12.4.
Stacks of large printed sheets are cut to size in this guillotine-type paper cutter. The vertical bars of the back gauge can be seen in the center. The distance from the knife to the back gauge is adjusted with the micrometer handwheel in the front.
(Source: Chandler & Price, used with permission.)

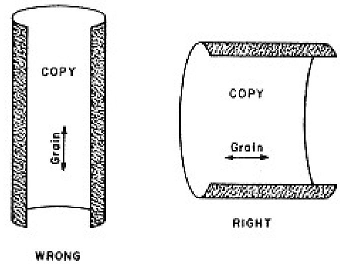

Figure 12.5.
The grain of a label can be determined by wetting one side, so that it curls toward the dry side. The direction of the grain will be the axis of the curl as shown.

eration of a labeling machine and most often it is required that it be in the horizontal direction (see Figure 12.5). Some machines, however, work best with the grain running vertically, especially in the case of P-S or heat-sensitive adhesives. The direction of the grain can be determined by wetting one side and noting the direction of the curl. The grain direction is always parallel with the axis of the curl.

Paper labels can be printed with the most sophisticated designs by a number of processes and will produce a faithful reproduction of the original artwork. The disadvantage of paper labels has been their appearance of being "tacked on" and not an integral part of the package. They also are vulnerable to scuffing, wrinkling, blistering, and lifted or curled edges. This drawback has been offset in recent years, at least for molded plastic bottles, by the development of in-mold labeling that bonds labels to a recess in the plastic surface. The containers then become product-dedicated, of course, which can have a cost impact on empty-container storage and for eventual recycling depending on whether the label material matches the bottle.

Film

Flat film labels, usually P–S, and film bands that are stretched over a container or shrunk in place are a relatively new and growing innovation in labeling techniques for bottles and jars.

Polyester film has the unique capability of filling three roles in labeling. It can serve as the carrier web for P-S labels of any material. It can be used as an over-laminate to impart sparkle and prevent scuffing of paper labels where the importance of the label data warrants the extra expense, and it can be used as a transparent label in its own right. Transparent P-S polyethylene terephthalate (PET) labels in 1- to 2-mil (25.6- to 51.3-   m) gauges are currently popular for toiletries, cosmetics, personal care, and even pharmaceutical products. It can be surface or reverse printed and, when metallized, has a mirror-like quality.

Stretch

Stretch labels are made from sleeves of low-density polyethylene, polypropylene and polyvinyl chloride (PVC) in roll form with perforations between labels. Special equipment is used to pull the labels over a stretching mandrel and down on to the package. Gauge is about 2 mils (51.3   m).

Shrink

Shrink labels are made of 3-mil (76.9-   m) PVC with unidirectional shrink characteristics. These labels can be applied by hand or with automatic equipment. When sent through a heat tunnel, the labels shrink up to 50 percent to hug the container contour.

Usually reverse-printed on the inner side to prevent scuffing, shrink labels are popular on bottled goods and, now, also are being seen on cans, especially the new contoured shapes (see Chapter 10, Metal Containers).

If the container is opaque, the label printing may be transparent. However, often the base label color (the last one applied) is an overall white or a solid color to show off the decoration against a transparent container. Metallized films are printed on the outer surface over the metallization. Both film and paper labels also may be printed over an opaque background on the back so they can be read through a transparent container—another method for getting more space to accommodate increasing amounts of copy.

Foil

It is nearly always necessary to laminate foil to paper so that the labels will work properly in labeling machines. Even so, there will be less springback than with plain paper because of the dead-fold characteristics of foil, and this may affect machine operation. The foil/paper lamination should total between 0.0025 and 0.003 in. (64.1 and 76.9   m) in thickness for best results. Laminations of paper and foil in the United States are specified by the basis weight of the paper and the thickness of the foil, for example, 40 lb/0.0007 in. (18.1 kg/17.9   m) (basis weight being the weight of 500 25-by-38-in. [63.5-by-96.5-cm] sheets).

Special inks are required for printing on foil, and it may be necessary to use a primer as well to get good adhesion (see Chapter 3, Films and Foils). Tinted lacquers also can be used to simulate gold or copper. It is difficult to get a good white color on foil, which usually takes on a gray appearance. For this reason it may be wise to avoid large white areas. Embossing is possible, but it may interfere with stacking and feeding of the labels in the labeling machine and can cause blistering problems. Pebble embossing, on the other hand, is sometimes used to improve the adhesion of the label to the bottle. Pebble embossing is an overall treatment, whereas registered embossing is a spot treatment.

Adhesives that contain solvents cannot dry as quickly through the foil as through a paper label, so heat-sensitive coatings often are used for such laminations. The appearance of a well-printed foil label is superb, and the bright reflective surface adds glamour to almost any package. However, foil labels are notoriously difficult to run and wastage is high.

The reason is that the solid foil surface is relatively impermeable, unlike the opposite paper side. Thus, changes in humidity in the environment can cause severe curling in the direction of the foil surface. The answer to this problem is humidity control from the minute the rollstock is created until labels are applied to the surface of a package. This goes for non-foil printed labels, as well, which may be coated on the printed side with impervious gloss and anti-scuff coatings.

Label Storage

In storage and transport, labels should be wrapped in vapor-tight materials. It also helps cut labels stay flat if chipboard discs are positioned top and bottom and held in place by the wrappings. In the labeling area of the packager, label rolls of all kinds should be stored in an air-conditioned room or a tight cabinet (for very small labeling operations) that is held to 70 F (21 C) and 70 percent RH, a standard industry atmosphere in the press rooms where labels are printed.

Label rolls in these rooms should be stored on pegs set into a false wall that is separated from the building wall and never on the floor or on pallets lying on the floor where external moisture can migrate.

Since corporations are almost universally loathe to spend money for air conditioning in the labeling area, (which would also keep the operators in better condition), the label storage room should be as close to the labeling operation as possible and only one roll of labels per machine should be removed from storage at a time. These precautions go a long way toward eliminating the problems that lead to the labeling operation being termed the major cause of downtime on a packaging line.

In the case of foil labels, another solution is metallization of paper label stock, which gives the appearance of foil when properly applied, but is still somewhat permeable to water vapor. However, improvement though this is, it does not discount the need for humidity control for all types of stored labels!

Types of Labels

As shown in Table 12.1, labels come in several forms: rollstock, cut, and folded that, today, often can look like miniature booklets.

Rollstock Labels

Typically 16-in. (40.64 cm) in diameter on a standard 3-in. (7.62-cm) core, rollstock labels come in two styles: a solid web of labels that are individually cut from the roll just before glue application or heat-sensitive adhesive activation; and P-S labels that are peeled from a carrier web and applied. Rollstock labels are exceedingly effective for high-speed long runs. Many machines can be equipped with dual roll stands and automatic splicers that enable continuous operation over extended periods. P-S rollstock labels also cause no mess from glue spills and eliminate sometimes extensive end-of-shift clean-up time.

Another advantage of rollstock labels is a greater degree of safety against a wild label occurring in the roll. The rolls also can be easily and automatically inspected off-line by the user to double check the label printer's own QC. So important is this in the field of pharmaceutical and medical packaging that

TABLE 12.1. Comparison of Labeling Systems.

	Label Type				
Characteristic	Plain, Cut	Heat-Seal, Cut	Plain, Roll	Heat-Seal Roll	P-S, Roll
Ease of Operation	E	D	C	B	A
Changeover Time	E	D	C	B	A
Cost of Equipment	A	A	B	C	A
Cost of Labels	A	B	A	C	C
Quality of Printing	A-B	A-B	B	A-B	A-B
Ease of Code Marking	A	B	A	B	B
Servicing from Supplies	E	E	B	A	A
Avoidance of Label Mixups	E	E	A	A	A

A is best; E is poorest.

the Food and Drug Administration, Washington, D.C., now strongly urges the use of rollstock rather than cut labels and demands continuous 100 percent inspection of labeled containers if cut labels are used [1].

Cut Labels

Cut labels are useful for short runs and for labels with large dimensions, where a cold-or hot-melt glue is used for either functional or economic reasons. (P–S adhesives are more expensive.) However, cut labels must be applied with an adhesive and the clean-up time for such equipment is a cost factor that packagers should take into consideration.

Folded Labels

Multipanel folded labels are a recent answer to the ever-increasing need to supply the consumer with more information, either legally mandated data or instructions needed for the use and care of the product. The fanfolded booklets have become more widely used as bottled products have eliminated cartons, a packaging component that environmentally conscious consumers view as superfluous and which is a considerable expense for packagers. The folded units generally can be fed from magazines by pick-and-place devices and adhered to the container side or top by adhesives or supplied in P-S rollstock form.

Printing/Decoratin Processes

A broad variety of methods are used to apply information to packaging, including direct decorating of containers and printed labels. While labeling is generally less expensive, the choice between labeling and direct container decoration is often more of a marketing decision than one of economics.

Label printing processes include letterpress, flexography, gravure, lithography, silk screen, thermal transfer, hot stamping, and embossing—one or more of which are selected to suit the complexity and color requirements of the graphics and the degree of economy required by the application.

Letterpress

Noted for its crisp impressions of type, letterpress permits good color control with clear, sharp detail and is used today largely in the printing of rollstock labels, particularly those for pharmaceutical and medical products where small print must be highly visible and where precise consistency of imaging is necessary throughout the run. Presses can be a reciprocating platen, semi-rotary, or fully rotary. The equipment is relatively inexpensive. Printing plates are moderate in cost, and makeready is fairly easy (see Figure 12.6). Thus, it is favored by many small printers and a significant number of packagers, particularly in the pharmaceutical and medical products fields, where close inside control of packaging processes is required.

The printing plates can be metal or photopolymer plastic. Both conventional and ultraviolet (UV) inks are available. The process favors single-color designs since letterpress can handle only one at a time and multicolors require additional passes through the press and attendant registration concerns.

Flexography

The printing process in broadest use for packaging today is flexography. It is similar in nature to letterpress, except that the face plates are rubber or elastomeric and the inks are applied by ink-metering (anilox) rolls, which really are the key to the whole system and recent advances in flexo capability (see Figure 12.7).

The process has developed rapidly in better detail and faster press speeds. Equipment is relatively inexpensive and popular in small shops. It can be used to print films, foils, papers of all kinds, paperboard, and corrugated. It also can contain a laminating section to apply a second layer of material to the printed web. Multicolor printing is attained by linking separate printing stations, usually separated by individual drying sections.

The anilox metering rolls can be made of a steel cylinder coated with ce-

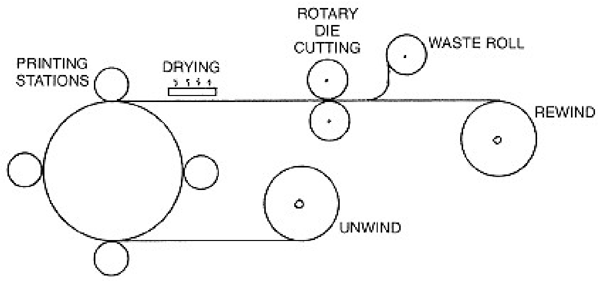

Figure 12.6.
Letterpress printing.

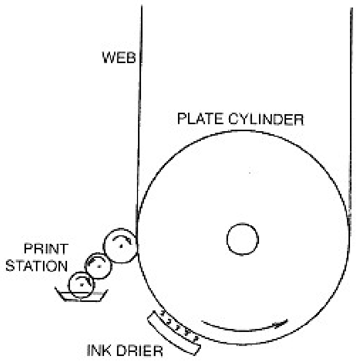

Figure 12.7.
Flexographic printing.

ramic and laser engraved with a pattern of ink cells or mechanically engraved and coated with copper and chromium. The ink-cell structures can be varied in pattern, size, and depth to create different effects with the low-viscosity, fast-drying inks used in this printing process.

Plates that were originally made from molded rubber are now largely photopolymer and constructed from a photosensitive material bonded to polyester. The relatively inexpensive rubber plates that require a metal engraving and material-transfer process work well, but can have problems of unequal thickness and dimensional stability. The photopolymer/elastomeric plates which substitute a photographic image and solvent “etching” process solve the previous dimensional problems and provide a longer life and improved printing quality and detail.

Lithography

Another offset process, lithography, is used to create sharply detailed and multicolor graphics principally for high-class folding cartons and labels for cans and bottles, where inks and varnishes can run to eight impressions. The process also is compatible with foil and is used for direct printing on cans. Most presses are sheet fed, but there are some rotary units to handle rollstock.

The process is planographic, meaning that the printing plate is a surface of uniform height. To separate printing from nonprinting areas, the aluminum alloy plates, (which have replaced the original stone surfaces), are treated to create ink-receptive areas for the printed design and water-receptive areas for the nonprintable surfaces. These plates are mounted on a plate cylinder as in flexographic printing and are inked and water coated for transfer to a blanket cylinder as in dry-offset printing. The stock is fed between the blanket and an impression roller that apply enough force to transfer the ink cleanly to the labelstock (see Figure 12.8). In direct printing on can stock, flat sheets are used with either conventional or UV inks, which are, respectively, oven-baked or light-treated to set the printed image.

Because of the transfer method, the stock must be very smooth. As a result, it's a major application for cast-coated paperboard for fine cartons. Litho printing can exceed 220-line screen in detail and while the process is relatively economical, the more expensive stock makes it suitable mainly for high-quality cartons and labels.

Gravure

Gravure printing (also called rotogravure) is used for intricate designs and colors but requires long runs in the million-plus range to amortize the high cost of the engraved rolls. Color laydown is excellent, Makeready time is very short and printing results are very consistent (see Figure 12.9). Gravure has been termed the Cadillac of package printing, mainly for cartons.

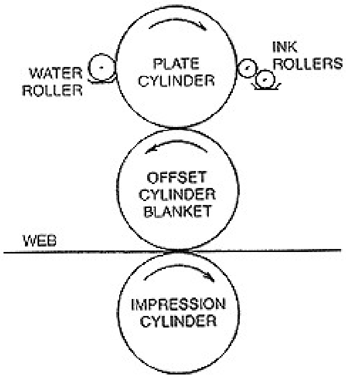

Figure 12.8.
Lithographic printing.

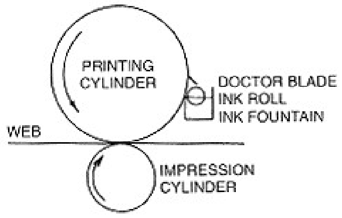

Figure 12.9.
Gravure printing.

The process chemically or mechanically incises small and large cells into the surface of a copper-plated steel cylinder, which usually is chrome coated afterward for wear-resistance. Today, electromechanical, laser, and electronbeam engraving have largely replaced traditional chemical etching. Electromechanical engraving, while expensive because of the equipment involved, permits use of digital data and is compatible with modern computerized design methods.

Printing is a web process with the roll immersed in a pool of low-viscosity ink that is wiped from the outer surface by a doctor blade, leaving the cells filled with ink. The rollstock is fed between the engraved and impression rolls and the ink is drawn directly from the cells onto the stock, often by creating different electrostatic fields in the stock and printing rolls. The thin inks, often containing a volatile solvent, dry between printing stations, thus avoiding the problems of wet-on-wet multicolor printing as in offset.

Dry-offset

Dry-offset printing of containers (also known as letterset printing) is a major decorating process in packaging for such round elements as bottles, cans, caps, closures, cups, jars, pails, and tubes. The high-speed process can apply multicolor line copy, halftones, and process artwork in up to six colors in a single pass. The paste inks are capable of variable laydown from light to heavy. The process is economical for long runs. Many variety store and industrial items are decorated in this manner, but dry-offset is not often used for toiletries and other luxury items.

In operation, the standard or UV-cured ink is transferred through a series of tangentially contacting rolls, including a printing-plate roll with a raised image, which then transfers the inked image to a rubber "blanket" roll, which properly positions all of the colors to be applied at the same time to the packaging container (see Figure 12.10 for the sequence of operations). Each color is transferred in the same way to the single blanket by separate inking stations. The process is similar to offset lithography, but is called "dry" to differentiate it from the water used in the latter process to separate image from nonprintable areas.

The containers, which must be made to close tolerances, are positioned very accurately on spindles spaced around a turret, which has stations for air cleaning and, if necessary, surface flame or corona-discharge treatment. Notches, bottom lugs, or other marks on containers are used to register the printing. The inks are cured on-mandrel in a curing unit or transferred to an appropriate infrared or UV drier. Speeds in an indexing machine are up to 400/min for cups and the like, up to 1,200/min in continuous motion for bottles and cans.

Hot Stamping

Often used in conjunction with silk screening, hot stamping (also called leaf printing) is an excellent way to apply rich colors and metallics like gold and silver, usually as extra components or decorative additives to designs already existing on cartons and labels. While akin, hot stamping is not the same as heat transfer (to be discussed later). Hot stamping consists of designs of foil and/or colored inked patterns that are mounted on a release web with the design facing outward. A die that has a surface configured to the printed web then releases the multilayer design (see Figure 12.11) and transfers it in register to the desired carton or label surface. Hot stamping also is a popular method to apply variable information on-demand to paper, paperboard, and films, including pharmaceutical packaging. (Print-on-demand coding is discussed in detail on page 418.)

The construction of a hot-stamp design is complex and involves, from the inside out, a carrier web (generally a polyester film or cellophane backing), a release coating, protective lacquer, the print foil or color, and an adhesive.

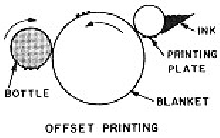

Figure 12.10.
Dry-offset printing.

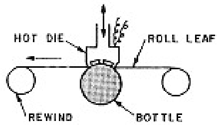

Figure 12.11.
Hot stamping.

There are two applicating methods. One is direct stamping in which the hot die contacts the carrier web on the opposite side to the decoration, pressing the multilayers against the package or label substrate to be decorated. The die can be flat or contoured to match the surface. The hot die makes contact with the full substrate surface for a timed heating period that enables the released design and outer layer of adhesive to be heated and selectively attach to the substrate in an intermittent operation.

There is a roll-on technique, too, for round containers in which the web is tracked across the substrate surface and held to it in orientation by rollers. The flat die is moved across and in contact to the top of the web and container in a timed sequence that creates a continuous-motion operation.

Transfer Processes

There are several techniques to transfer inks from a preprinted carrier strip of paper to a container. Some are more elaborate than others and require more fixturing to hold containers in the proper position. However, in the main, the process involves a succession of inks that are laid down on a release-coated web in reverse order with the surface varnish or color against the web and the final outside coating being a transparent heat-sensitive adhesive. The printing can be by almost any desired process. A thermoplastic transfer coating or lacquer, located between the printing and the carrier web, melts under pressure of a die that conforms to the substrate contour and the printed design selectively transfers to the container against which it is pressed and adheres due to the heated adhesive (see Figure 12.12). Surface treatment by either flame or electrostatics may be necessary to ensure label adherence for this type of labeling.

In the past, transfer printing has been limited by an unattractive, shiny "halo" around the graphics caused by the carrier varnish. In 1996, an improved process that eliminates the halo, was introduced, an advance that should lead to expanded use in the labeling of bottles, jars, and other molded shapes [2].

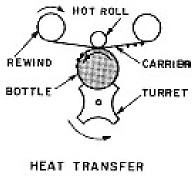

Figure 12.12.
Transfer printing.

Silk Screening

Screen-printing techniques go back to ancient times in Egypt and China, where inks were brushed through screens to form decorations on walls, fabrics, and papers. In the modern process, a viscous ink is forced through design portions of a fine-meshed screen with a squeegee (see Figure 12.13). The screens are made of silk, polyester, nylon, or wire cloths stretched over a frame with the object to be printed fixtured in registration underneath. The pattern is created by covering the screen cloth with a light-sensitive emulsion. The screen is then covered with a positive image of the design and the screen is subjected to a brilliant light that hardens and cures the emulsion not protected by the opaque design. The uncured emulsion is washed away leaving the open design pattern on the screen, which permits the ink to pass through and onto the object. Ink laydown is heavy and detail is limited to about an 85-line/in. (25.4 mm) screen. Initial costs are quite low, because silk screens are relatively inexpensive. The process is well suited to short runs. Ink coverage is excellent, and the printing is slightly raised above the surface of the container, giving it a special elegance.

Silk-screen printing of labelstock has been limited to solid colors and line work in the past. However, for at least five years now, complex halftones have become possible. The process is used quite extensively for cosmetic items. Typical cost is about 1 cent per color on small labels.

Silk screening also is used to decorate cylindrical containers, which can be

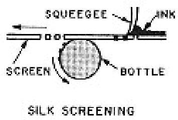

Figure 12.13.
Silk-screen printing.

printed in the round in one pass on the machine. If more than one color is to be used, it is necessary to have an indexing socket on the container bottom or a break in the threads, which can be picked up by the printing machine so that one color can be registered with another. UV inks are now available and drying stations between printing modules make multicolor designs more practical. With special fixturing, a wide variety of shapes can be decorated with this process at speeds in excess of 100/min. on automated equipment.

Pad Printing

A special form of transfer decoration that is almost a hundred years old, pad printing was used originally in the Swiss watch industry, and derives its actions on techniques employed in both gravure and offset printing. Its main impetus in packaging and other fields of product decoration came in the 1970s with development of better equipment to exploit its capability for decorating oddly shaped products. It is extensively used to decorate caps and closures.

There are three basic elements in the process: (1) a perfectly smooth ground, lapped, and engraved plate, called a "cliche" made originally from soft copper, which was later improved by chrome plating, and today is hardened steel for long runs and plastic for short runs; (2) the usually coneshaped transfer pad, originally made from soft gelatin and now made of silicone rubber; and (3) the fixture or tooling that holds the object to be printed. The latter still can be a fixed station for semiautomatic operations, but increasingly is a series of fixtures mounted on a circulating conveyor.

The operation is essentially a gravure printing technique. A spatula or brush sweeps a layer of ink over the cliche in which the design is engraved to a depth of 0.001 in. (25.6 m). Then, a sharp "doctor" blade scrapes the cliche clean, leaving ink only in the engraved pattern. The pad then descends onto the image, picks up the inked design, and transfers it to the package or packaging component by pressing it onto the surface. The pad completely releases the ink pattern, allowing "wet on wet" printing without drying each ink and without smudging or distortion (as in offset printing). Both electromechanical and hydraulic equipment are now available, capable of speeds to about 30 pieces per min in one-head equipment to 300 per min in multihead rotaries.

In-mold Labeling

A cost-saving method for the packager is the in-mold labeling process (IML), which permits application of body labels during the plastic molding operation. First used in the 1970s by Procter & Gamble Co., Cincinnati, the technique eliminates labeling operations at the packaging point along with mislabeling, cleanup, and machine maintenance. It also can reduce inventory and permit higher line speeds.

In-mold labels are coated on the reverse side with a heat-activated adhesive. In container blow molding, front and back labels are fed from magazines and positioned by robotic devices in vacuum ports, which hold the labels in place in the mold. The hot bottle parison contacts the labels during expansion of the "bubble," activates the adhesive and flows up and around the edges of the label. As a result, the label is actually embedded in the bottle wall, protected from scuffing and tearing.

In-mold labels generally are gravure-printed with the ethylene-vinyl acetate (EVA) adhesive applied to the backside of the web at the last machine station. However, narrow-web printing presses for flexo, rotary letterpress, and hot stamping also may be used. As a result, both film and paper IMLs have found ever broader usage for all kinds of food, household chemicals, and healthcare and personal products.

Print-on-Demand Coding

Print-on-demand labels are being used where a great variety of changeable label information must be continually printed on small quantities of labels. To do this by conventional off-line printing processes in which each variation requires a product and shipper label in inventory, for example, would be ruinously expensive. This is particularly true of such product data as size, color, and style that may vary individually from package to package.

The answer has been creation of compact on- and off-line printers that supply both alphanumeric data and/or the ubiquitous bar codes, now used to identify almost every stock-keeping unit (SKU) in both retail and industrial goods. While these compact printed identifiers are read by both fixed and portable electronic scanners, there are situations where the more usual printed descriptions also are necessary. Therefore, product identification labels are almost always printed in both coded and alphanumeric fashion (see Figure 12.14 for an example).

Meanwhile, almost all retailers—large and small—are increasingly insistent that the data on both shippers and retail containers be totally accurate and completely readable by the electronic scanners used in *their* storage, transport, and sales outlets. Retailers are applying severe penalties for noncompliance, too.

Thus, conservative packagers tend to apply coded data in a strongly contrasting color to that of the labeling substrate. Black ink on white labelstock is tops for application to both product and distribution packages. To satisfy

Figure 12.14.
Information stored in memory can be used to operate a dot-matrix printer for small quantities of labels. Borders and bar codes are part of the stored data for every product in the line. Purchase order number can be added before printing each batch of labels. (Source: Fleishmann Distilling Corp., used with permission.

warehouse and distribution needs for visibility on stacked product, labelers are now available that print longer labels with two sets of the same data and then mechanically apply the labels around case corners so that the information shows on both a side and an end panel.

The target of all this development is to present, in the most readable way, the information contained in a bar code, which is mostly a series of thick and thin machine-readable lines. The data is used for verification, tracking, sorting, recording sales, and inventory.

There are many different systems, but the codes most generally used are the Universal Product Code (UPC) found on most retail goods; "Interleaved 2 of 5" (interleaved means that spaces between the bars as well as the bars themselves are read), which supplies much of the information on shipping-case labels, and such industry-mandated symbologies as the "Code 39" used on a majority of healthcare products. Government defense agencies and depots also require all unit packs and outer containers to carry data in Code 39. Just coming into use are two-dimensional symbologies that condense more information into a smaller space (Figure 12.15).

There are many types of label printers that print bar codes. On-demand label-printing techniques range from manually applied stencils and letter-press, offset, and thermal printers to noncontact ink-jet and laser devices. These technologies and their associated computer storage of label and code formats can be operated either directly on the packaging line or as an off-line

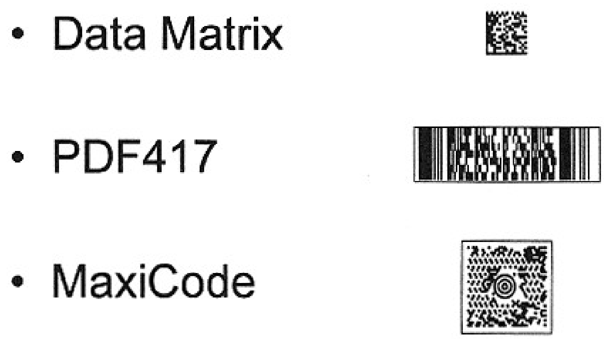

Figure 12.15.
Common two-dimensional symbologies include PDF 417, Data Matrix and MaxiCode, used, respectively, for primary packaging, shipping labels, and small parcel delivery.
(Source: CiMatrix, Canton, Massachusetts, used with permission.)

office operation in which labels are printed in sheets for manual application to small package quantities.

However, on-line printing of information requires more than a good printing machine. Stable conveyors, close control of positioning, and regular preventive maintenance of all associated equipment is essential. For example, drop-on-demand, impulse ink-jet printing heads must be located within 0.25 in. (6.4 mm) of the printing surface and require frequent cleaning.

Dot-Matrix

Dot-matrix printers were the first medium-speed devices used to any great extent. They apply dots to a labelstock by means of little hammer heads that either span an entire page or are shorter and shuttle back and forth on a track. Usually 9 or 24 pins operate in clusters to form the wide and narrow bar code lines that in this type of printer have an *"X* dimension" (the smallest readable element) of 0.012 to 0.020 in. (0.3 to 0.51 mm). The ink is supplied by a ribbon, which must be checked frequently to ensure that enough ink is left to produce a readable code. Since code bars are formed by a series of connected round dots, small unprinted areas at their points of tangent may lead to a misread unless the images are carefully printed and aligned. However, today's high-speed line printers are capable of reproducing both alphanumeric characters and perfectly linear bar codes.

Direct Thermal/Thermal-Transfer

Among the most popular bar-code printers are direct thermal and thermal-transfer. Direct thermal printing, the older technology, was quickly adapted to printing bar codes. In this technology, a printhead the width of the label stock is equipped with a "linear thermal array" of elements that each can be heated under computer direction to produce tiny dark dots on chemically treated labelstock as it passes underneath. The result is bar codes and alphanumeric characters created at 2 to 5 in./sec, that can have an *X* dimension as small as 0.005 in. (0.13 mm).

The labelstock can be a white, organic composition that is difficult to scan with infrared scanners and is subject to attack by industrial chemicals or a slightly off-white inorganic stock that to some is not as attractive, but which scans well and is quite resistant to chemicals. In either case, the labelstock must be matched to the printer, and it is best to obtain the material from the printer manufacturer. Thermal labels should never be exposed to direct sunlight or to temperatures above 140 F (60 C).

Thermal-transfer printers, while closely related in technology, use plain paper stock and melt a waxy ink from a ribbon and deposit it on the label at speeds to 12 in./sec. (30.5 cm/sec) with *X* dimensions down to 0.006 in. (0.15 mm). This method avoids the environmental problems of a coated stock associated with direct-thermal printing. However, since ink transfer occurs at about 150 F (66 C), this operation must be located in an area secure from higher temperatures.

Ink-Jet

The ink-jet technique is growing at a rapid pace because it is now capable of providing very readable large or small characters as well as being fast in application and easy to clean and maintain. The state of the art is such, today, that it is indeed possible to print almost any important data of any practical size directly on the product or shipping package.

Laser

Another on-line option is a laser coder. Equipment cost is high, and some materials, such as polyethylene, are transparent to the laser beam, unless specially treated. Nevertheless, this method is being used where the permanence of the code and the capability of incising through a surface color to reveal a contrasting sub-surface color is possible, warranting the higher capital investment.

Holographic Labels

The hologram, an embossed and printed design that creates a flat image, which is three-dimensional in appearance, was invented as a security and anti-forgery device for bank and currency documents, postage stamps, credit cards and licensed products like clothing with the World Series logo. The process cannot be photocopied and is said to be very difficult to counterfeit. Its usage in packaging as a form of decorative and eye-catching labels has been much more recent and, despite its high cost, is growing. Currently, the holograms used in packaging accounts for about 17 percent of the $300 million worldwide consumption of holograms.

The origins trace back to the 1960s and Drury H. Baughan, an expert in optical imaging and materials converting, who founded Old Dominion Foils, a printer of aluminum foils. The company and Baughan were acquired in 1981 by American Bank Note Co., Elmsford, New York, to help develop holographic printing for security applications. In 1985 Baughan left ABN and started James River Products, Richmond, Virginia, to create the precision machinery required to emboss and print holographic designs.

Holograms are created in two ways: embossed and volume. In the volume system, each hologram is exposed on a photosensitive medium and then developed, capturing the holographic data inside the system. The substrate is thick and expensive. Although superior in appearance, the process is slow and limited to narrow webs and not currently feasible for packaging.

Embossed holograms, on the other hand, can be created by various embossing processes and store the data on the surface of the photosensitive material. Like printing, a plastic web can be run through the embossing device accompanied by heat, pressure, and a radiation treatment. There is no ink, however, the colors being formed by diffraction of white light from the surface. Holograms can be actual photo images or nonspecific designs that reflect light in dazzling patterns and are created by multilevel two-dimensional designs, by stereographic multi-photographs, or by dot-matrix-generated diffractive pixels or scribed diffractive gratings. They also can be produced by embossing in hot-stamp foils or produced on paper or film substrates as labels applied to packaging with pressure-sensitive adhesives (see Figure 12.16).

Packaging applications to date have included labels for bottled water, soft drinks, fish food, bandages, and gasoline treatment; bags for snacks; cartons for cereals, toothpaste and liquor; and magazine-page ads for packaged goods, all of which were reportedly very successful in boosting sales.

Cost of a label hologram tends to fall in the 1- to 3-cent range, but can run as high as 10 cents each [3]. Minimum order size for a generic hologram is one 1,000-ft roll, which may contain 2,000 to 6,000 one-up images [4].

Figure 12.16.
National Patent Medical used a holographic label to launch Stat Strip bandages. The hologram not only captures attention, it also demonstrates the two-stage technique for opening the package.
(Source: Polaroid Corp., Cambridge, Massachusetts, used with permission.)

Label Design

Four factors determine the efficiency of label application: the label, the container, the adhesive, and the machine. For best results, standards should be established for each of these elements, and strict adherence to the specifications should be required.

The dimensions, stock, and grain direction of the label need to be specified as well as the type of adhesive, viscosity, and conditions and time for storage. Surface treatment and temperature of the container are important. If containers are brought in from a cold warehouse and sent directly to the filling line, condensation of moisture from the air can cause trouble.

Machine settings and general maintenance, particularly cleanup of glue pots, dilution of glue, and protection from contamination and drying out, should all be spelled out in the process specifications and followed for consistent results on the production line.

The choice of paper stock will depend on the appearance desired, method of printing, and resistance to moisture or other conditions in retail stores and at the point of use, along with resistance to the product, scuff resistance in shipment, and the requirements of the labeling equipment.

In the United States, uncoated papers are used for economy and because they are less likely to curl, but most often the stock is coated on one side for better appearance, printability, and wear resistance. A fast-growing label form is rollstock P–S-adhesive-coated labels that apply faster and with less mess.

Two-side-coated papers usually are more difficult to make adhere, because the glue does not penetrate readily into the paper. Back treatment is sometimes used by label manufacturers before the application of remoistening or heat-sensitive adhesives to prevent solvents from penetrating the paper. Uncoated papers come in various surface finishes and degrees of smoothness.

For greatest accuracy, labels should be die-cut, although guillotine-cut labels can be held to very close tolerances. Each time a die is sharpened it will "grow" slightly, so that over a period of time the labels will become larger. If a multiple die is used, it may also be necessary to have the supplier keep the labels from each die separate to ensure uniform results on the labeling machine.

Die cutting also work-hardens the edges of foil so that there is less tendency for these labels to curl. A label will adhere best to a flat surface. The greater the curvature, the more difficult it will be to keep label edges from lifting. For this reason a label should not extend too close to a corner or the shoulder of the bottle (see Figures 12.17 and 12.18).

Use the lightest weight of paper stock that will work on the machine. Usually a 50-lb (22.7-kg, 0.003-in., 76.9- m) lithograph stock, coated on one side, will give the best results; but 60-lb (27.2-kg) is more commonly used.

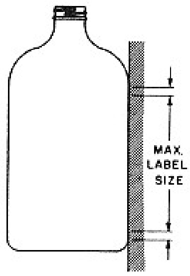

Figure 12.17.
Holding a flat edge against a bottle will show where the straight portion begins and ends. The label size should be less than this amount to allow for variations in placement.

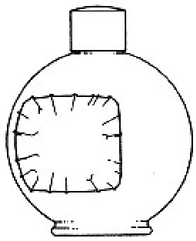

Figure 12.18.
A label will not lie flat when it is on a compound curve, that is, one that curves in two directions at once, or when it extends up onto the curve of the shoulder.

These basis weights refer to the weight of 500 sheets measuring 25 by 38 in. (63.5 by 96.5 cm). A variation of 5 percent in the thickness of the paper is generally considered an acceptable commercial tolerance.

Label Costs

It is difficult to determine the cost of producing labels, since they come in such a variety of types and sizes. However, for purposes of general information it can be said that a typical artist's sketch for a new label may cost about $500 of computer time. Converting this to a black-and-white mechanical drawing, suitable for reproduction, will cost another $125. Printing plates will vary according to the process used, costing anywhere from $50 for offset plates, $200 for flexo plates, $250 for web letterpress, to $3,000 for a gravure cylinder.

The cost of the stock for a typical plain paper label is around 33 percent of the total cost. Film is about 42 percent of total cost. As an example, a 4   4 in. (10.2   10.2 cm) rollstock label with two colors and a varnish and in a 15-million quantity will cost $35.34/1,000 in gloss paper and $50.65/1,000 in a polyolefin film. Plates for both cost about $250. However, the industry is slowly changing over to computer processing systems that can create a label design and go directly to printing without intermediate steps and plates.

Running costs for printing labels will range from $7 to $50 per 1,000 depending on the quantity, the number of colors and the base material. The costs of plain paper labels compared with those for heat-seal and P-S labels are in a ratio of about 1:1.5:3.

Adhesives

The amount of adhesive in a package is a relatively small part of the total structure in terms of the percentage of the final cost. But just as a chain is only as strong as its weakest link, so the package may be only as good as the adhesive that is used to form or close it.

The importance of the adhesives industry in the total packaging field is indicated by a global output of about 8.82 million tons (8 million metric tons) per year. The U.S. share is about 320,000 tons (290,496 metric tons) per year. About 45 percent of the U.S. share is in vegetable-type water-based adhesives. Hot-melts account for about 15 percent, solvent-based for 16 percent, reactive for 15 percent, and animal glues for about 9 percent. More than 75 companies make adhesives, but five giants do 65 percent of the total business.

Adhesives are used in almost every packaging industry manufacturing and assembly operation. Thus, the significant trend in adhesive use for packaging in the last few years has been to eliminate or minimize the use of solventbased formulas in favor of water-based as an environmentally correct move. This has led not only to continued strong use of the water-based adhesives in packaging but also the great growth of hot-melt, which is a 100 percent solids system. The latest challenge is to create adhesives that do not impede the recycling of used packaging.

Principles of Adhesion

Before discussing specific packaging adhesives, however, it is necessary to know something about the principles and theory of adhesion. The objective in joining materials by means of an adhesive is not to seal the substrates as close together as possible, but rather to create a sandwich of substrate-adhesive-substrate. Although it may be desirable to minimize the amount of adhesive, it is poor practice to over-thin it by pressure or dilution.

Rough or porous surfaces with “tooth” can be joined with adhesives that harden or crystallize. Very smooth surfaces on glass or plastic containers, on the other hand, present a very different problem. For these it is often better to select an adhesive that remains flexible and a little tacky. This provides what is sometimes called a “suction bond.” It may be necessary to treat some plastic surfaces, particularly the olefins, with a flame or corona discharge to oxidize the surface. The use of primers to improve the bonding characteristics of certain films and foils is also important, particularly in the area of laminations, where extrusion techniques provide economical combinations of flexible materials. Do not overlook the presence of plasticizers or other additives in film substrates, which may have an adverse effect on adhesion. A typical dextrin adhesive will cost about $2.45/gal ($0.65/L). One gallon (3.79 L) will cover about 50,000 $in.^2$ (322,580 cm^2) if applied by hand, and 100,000 $in.^2$ (645,160 cm^2) if applied by machine.

Theory of Adhesion

The mechanism of adhesion is not clearly understood, but appears to be a combination of physical and chemical forces. The following highlights of a very complex subject may help provide a better understanding of adhesive phenomena.

Mechanical bonds will result from the penetration of adhesives into porous materials. When the sealant soaks into the fibers and hardens, an interlinking produces a bond whose strength depends on the cohesive forces within the adhesive or the substrate, whichever are stronger. The viscosity of the adhesive and the porosity of the material will, of course, determine the amount of penetration into the substrate.

If the surfaces to be joined are not porous, molecular forces rather than mechanical interlocking forms the bond. In this case the roughness or smoothness of the surface must be considered, for it is an important factor in adhesion. There is an ideal angle away from the parallel for the slopes of "hills and valleys", which make up the roughness of a surface, that will impart maximum holding power for the free energies of the specific materials involved. For paper or any other cellulose material, for example, this angle has been calculated to be 43 . The maximum work of adhesion in this case is between 0.002 to 0.003 lb/in. (0.4 to 0.5 g/cm). So the adhesives should have a surface tension within this range. Shrinkage of the adhesive as it sets up will reduce the effectiveness of these forces, but may be minimized to some extent by working with the adhesive at a higher temperature and chilling it as quickly as possible after it is applied.

On perfectly smooth surfaces, however, the reverse may be true; that is, a low temperature and slow cooling will be less likely to set up stresses in the adhesive that tend to break up the intimate contact at the interface. A preliminary indication of this can be found by coating only one side of strips of the substrate, exposing them to various conditions of temperature, humidity, and aging, and then checking the condition of the adhesive. As the surface becomes smoother, the molecular attraction between the adhesive and the substrate takes on a greater significance.

There are several forces at work in these infinitely small spaces between the atoms and molecules, and the effectiveness of these forces is dependent in large measure on the distances involved. The "wetting" effect of the adhesive is very important in bringing the materials into intimate contact. Some adhesives have reactive groups in the molecule which can form primary bonds with the substrate. Examples such as oxirane, isocyanate, and cyano work better at the lower molecular weights, spreading out and giving a good wetting before they cure. When silicones are present as mold release agents, there is interference with the chemical bonding, due to a preferential orientation of electron-induced fields toward the oxygen atom next to a dimethyl silane group, which has room for additional electrons in the rho subshell of the oxygen. The "molecular diffusion" of one material into the other, which is on a much smaller scale than the "penetration" previously mentioned, is indirectly proportional to the two-thirds power of the molecular weight, and increases with temperature and time. This type of diffusion is more pronounced with polar compounds, provided the polar groups do not drastically interfere with the mobility of the molecular chains. Branchiness of the molecular chains also favors diffusion, and is proportional to the two-thirds power of the number of effective branches.

"Dispersion forces," which are on a still smaller scale than "diffusion" phenomena, result from the changing position or "dispersion" of the electrons surrounding atoms that are in close proximity. This decreases with the inverse seventh power of the distance and becomes insignificant beyond a distance of 4.5 Å (0.00045 m). For comparison, carbon atoms in a chain are 1.5 Å apart (six-billionths of an inch).

"Electrostatic forces" of polar groups are in addition to the dispersion forces and three or four times as great. The amount of such energy can be demonstrated by the potentials that are developed in peeling polyvinyl chloride or the cellulosics from a glass surface. The discharge potentials build up to several thousand volts. One other factor that should be mentioned, although it is less significant than those already discussed, is "van der Waals" forces. These forces arise from the attractions that come into existence because of dipoles present in polar molecules. They are less than a tenth the power of a covalent bond, such as a chlorine-chlorine bond.

Types of Adhesives

The word *adhesive* generally is taken to include the whole field, although in its narrowest sense it refers to synthetic resin emulsions. The term "glue" usually refers to adhesive from animal sources, although vegetable materials sometimes are included in this category. "Paste" and "mucilage" are nearly always of vegetable origin, and are used exclusively with paper products. "Cement" is a solvent type of adhesive for bonding such materials as leather, rubber, glass, etc.

The largest segment of adhesives used in packaging are water-based "natural" compounds, almost the only adhesives available until after World War II. These are starch (cornstarch in the United States), casein from cow's milk, animal glues, and rubber latex adhesives. Growing ever stronger, however, are synthetic, water-based emulsion adhesives and hot-melts.

Starches

Starch pastes are made from corn, tapioca, potato, wheat, rye, and sago. Starches in their natural form are used only for paper and paperboard packages, particularly in the combining of corrugated medium to the liners, where gelatinized cornstarch bonds the two papers at very high rates of speed. This paste is also used however to make bags and adhere labels. More often these starches are converted by dry heat, acids, or enzymes into white or yellow-colored dextrins, which have a quicker tack and a higher solids content. The starch and dextrin adhesives are low in cost.

Dextrins

Dextrins for labeling are usually brown in color, relatively fluid in consistency, and generally on the acid side. They have good transfer properties and dry fairly fast, but are not waterproof. Borax may be added for quicker setting and better adhesion. The borated dextrins tend to string out, however, and do not work as well in machines. To tell starch from dextrins, an identifying test is made with a dilute iodine solution. Starch turns the test solution blue, whereas dextrin produces a red or brown color.

Ideally, dextrins should be used within a few months of manufacture, but may keep for a year or more under ideal storage conditions. Simple dextrins are the least expensive and have the best machining qualities of all adhesives and can be easily cleaned off equipment with warm water.

Tapioca dextrin is preferred for high-speed operations. Corn dextrin is lower in cost but does not set up as quickly. Starch ethers are a class of compounds that are used in making bags, and also as a remoistening adhesive. Special types of dextrin can be combined with polyvinyl acetate emulsion to improve lie-flatness in making envelopes.

Jelly Gums

Jelly gums for labeling are colloidal dispersions of modified starches. With fairly good resistance to high humidity and moisture, they generally are considered semi-iceproof. Jelly gums are rubbery and cohesive, white to reddish brown in color, and usually alkaline. Jelly gums are effective on hot, cold, wet, dry, greasy, or oily bottles made of flint, opal, or borosilicate glass and on most of the coatings used to resist scratching, except the silicones. Jelly gums are widely used in the food, beverage, pharmaceutical, and cosmetic industries. Animal jelly glues are formulated to be liquid at room temperature and to gel in cold water. They are used as iceproof gums for beverage bottles and while they have limited resistance to immersion in water are satisfactory in even high humidity conditions.

Caseins

Casein glue is a product of the dried curds of milk, sometimes combined with lime and other ingredients. It is prepared for use by mixing with cold water. There are two major packaging applications. One is as a dominant ice-proof and water-resistant adhesive for labeling glass bottles, that is also removable in the lye washers for returnables. The second is as an additive to adhesives for laminating foil to paper. Casein glue is amber to dark brown in the unpigmented form, slightly alkaline, and fairly fluid in consistency. For fast setting, it must be applied in a very thin film. Dilution with water is difficult without ammonia and, for greater water resistance, alcohol is sometimes used as the diluent. It is mixed with clay to make clay-coated folding boxboard. It has poor tack, but very good adhesion when dry.

Animal Glues

Animal glue is made from the hides and bones of animals, chiefly beef steers. Available in flake or granulated form, it is dissolved in water at around 140 F (60 C). Bone and hide glues usually are blended to make the standard product. It is generally medium brown in color, slightly on the acid side, and fairly fluid in consistency. It has good hot tack and fairly fast setting and drying rates. It makes a strong joint with paper and wood products, but has poor resistance to moisture, mold, fungi, and insects. Because of advancements in synthetics, its uses in packaging have been reduced, but it is still preferred as a remoistening adhesive for reinforced tapes used to seal boxes. It has good nonwarping qualities for the creation of set-up boxes and tight-wrapping when used hot at 140 F (60 C) with a minimum amount of water. To a limited extent it is also an iceproof adhesive for beverage labeling.

Resin Adhesives

Resin adhesives that are used in packaging generally are polyvinyl acetate emulsions. They dry quickly and make a strong bond with paper and many films, coatings, and similar nonporous surfaces. Two to three times more costly than dextrin glues, some formulations can be reactivated with heat if a heat-sensitive coating is needed. Other types will form an easy-release bond. Commonly used to attach film windows in folding boxes and envelopes, resin adhesives sometimes seal the glued lap in corrugated cases.

Pressure-Sensitives

These permanently tacky forms of adhesive are favored for labels because of their ability to adhere to almost any substrate and, despite their higher cost, because they shorten changeover times and virtually eliminate cleanup at the labeling machine which is a major cost factor in labeling with wet adhesives.

P-S labels are provided on a paper web with a silicone release coating. There are basically two types of adhesives based on acrylic formulations and rubber-resin blends. However, both types are modified extensively with other monomers and tackifiers to suit the needs of different types of applications and labeling surfaces.

While a majority of labels worldwide are still wet-glue, P-S labels are increasing. For the past several years in the United States, for example, growth has been up to 9 percent/year. The 1995 value of U.S. P-S label shipments was $3.24 billion in 1995.

There are a number of ways to apply P-S labels, but the start is to sharply break back the carrier web over a knife edge stripper plate, which automatically peels the label from the web. It can then be deposited directly after being picked up by a vacuum placer or drum or blown into place by an air jet. In the early days, accuracy of placement was a bit variable but today, placement can be guaranteed within ± 1/32 in. (0.8 mm).

Heat-Seal Coatings

Thermoplastic adhesives are special resin adhesives that are applied to paper and paperboard and can be reactivated by heat in a subsequent operation. This has permitted higher speeds in labeling, enveloping, and blister packaging. By printing the coatings in a special pattern, not only is the cost kept to a minimum, but easy-opening features can be built into the package.

Two types of adhesives are used on such labels. One is activated by a heated plate at the point of labeling and sets up instantly. The other, and more useful type, is a label coated with a delayed-action adhesive that has a longer “open time”; that is, it stays tacky for some time after removal of the heat source. Because the heating time can be extended and removed from the immediate area of labeling, machine speeds can be greatly increased. A typical example is to provide a preheating device as high as 400 F (204 C) followed by a 225 F (107 C) platen at the labeling station. However, the actual temperatures used depend upon the nature of the adhesive and the speed of the operation. These labels will adhere to plastic bottles and jars even if they are not flame treated, but sometimes have problems adhering to glass that has been silicone coated. These labels also virtually eliminate clean-up time.

Lacquers

Lacquers are similar to resin adhesives but are solvent rather than waterbased, higher in cost, and more difficult to use because of the fumes resulting from the volatile organic compounds. Made from such materials as cellulosics, vinyls, gums, and resins, dissolved in alcohol, naphtha, benzol, methyl ethyl ketone, or other organic solvents, their chief value is where the solvents are needed to "bite" into a smooth surface, as in the coating of plastic films. As with other solvent uses in packaging, lacquers are steadily being replaced by water-based counterparts due to the strict regulations governing solvent emissions established by both state and federal environmental protection agencies.

Cohesives

Self-seal adhesives, also known as cold-seal adhesives, are blends of waxes and latexes that stick to themselves, but not any other material. Their advantage is ease of adhesion without heat, which permits very fast machine operations. Cold-seal adhesives are usually pattern-coated on films or papers for wrapping operations and a major application is the pouch packaging of candies and cookies and the wrapping of chocolate bars, which melt at temperatures below that of heat-seal coatings. The materials must be kept free from dust, which can interfere with adhesion.

Latex

Latex adhesives are available as solvent solutions or water emulsions. Rubber latex is a high-cost material, so these adhesives are not cheap. Natural crepe rubber dissolved in naphtha or benzol is used as a temporary or permanent adhesive for paper, rubber, or cloth. Any trace of copper from the equipment will reduce the aging qualities of rubber adhesives.

Hot-Melts

Hot-melts made from thermoplastic resins such as polyethylene generally are used to tack things in place, rather than as the sole bonding medium, because of their high cost and the difficulty of spreading them in the short interval before the adhesive chills. One method is to use a flexible rope of adhesive, which is fed into a heated pump and immediately applied to the package. In another system, the adhesive is heated in a separate tank and circulated to the point of application through insulated tubes. Can labeling machines use hot-melts with instantaneous high tack for label pickup. For bag and carton seaming and sealing, especially with nonporous surfaces, hotmelts permit high-speed operations, because they set up much faster than cold glues, which require long compression sections on gluing equipment.

The definition of "hot-melt" excludes low-temperature waxes as well as high-melting resins, but spans an area in between. Temperatures ranging from 300 to 400 F (149 to 204 C) and viscosities from 500 to 15,000 cP would include most of the materials known as packaging hot-melts. Hotmelts are aggressively capable of adhering to almost any substrate and, therefore, can solve difficult problems in labeling. As an example, polyethylene terephthalate beverage bottles undergo a shrinkage of about 1 percent after being filled at 35 F (1.7 C) under an internal pressure of 90 psi (621 Pa), then showered at 130 F (54 C) until they reach room temperature.

To survive this cycle, a special label paper is laminated to polypropylene film and printed in a picture-frame pattern with a gravure roller. Labeling speeds of 200 to 300/min are achieved today for 1- and 2-L beverage bottles and 400 to 800/min for smaller juice bottles. The technology is said to be capable of 1,000/min and at least one beer line is running at 1,500/min.

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2. 1996. Clear ADvantage product literature from Avery Dennison, Framingham, Massachusetts, and Thermocol labeler product literature from Krones, Inc., Franklin, Wisconsin.

3. 1995. Price sheet from Crown Roll Leaf, Inc., Paterson, New Jersey.

4. Ibid.

Chapter 13—
Caps and Seals

Introduction

The smallest part of a package, and often the most critical, is usually the closure. The security of the whole assembly and the integrity of the contents are dependent upon the cap, fastener, or adhesive that is used to complete the package. Not only must the closure remain intact throughout the hazards of assembly, storage, handling, and shipping, but it also must be easy to open and reclose when it reaches the consumer. There is often a very narrow line between a closure that is easy to use and strong enough to travel, and one that fails in shipment or is nearly impossible for the average person to open.

In addition to its functional qualities, a closure can sometimes enhance the appearance of the package. A ribbon bow, an embossed metallized seal, or a decorative cap can provide the extra touch that spells the difference between success and failure in the marketplace. A message or brand identification can be included in the design of the closure, where it is most likely to be noticed. A closure is the finishing touch to the package, and it deserves special attention if it's to make the most of its prominent position.

Potential closure defects such as the fit of the cap on the container, appearance, color match, seal integrity, dirt, and mechanical damage must be controlled because of the vital part the closure plays in the total package performance. As a result, a thorough evaluation is more important here than for any other component.

History

Probably the first closures, used by the Greeks as early as 600 B.C., were of cork, which remained about the only closure material and design for more than 2,000 years.

The origin of the screw cap is lost in history. Bottles with threaded finishes are known to have been used, although rarely, because of the difficulty of making them in the early nineteenth century. The Espy patent, issued in 1856, disclosed a screw cap with a disk of cork that, when screwed down on the neck of a jar, brought "the said cork in compressing contact around the upper edge or mouth… the cork shall entirely cover the said mouth."

The Mason jar was patented in 1858 by John L. Mason, and his chief contribution was an improvement in the design of the thread on the glass container. He started his thread a little below the top surface and made it fade away before reaching the shoulder. Previously the top edge tended to break away and the bottom would jam the cap thread before the cap was all the way down.

The earliest aluminum cap, the Goldy, was used on catsup bottles after 1897. The roll-on screw cap was developed by the Aluminum Seal Company (Alseco) in 1924 and initially used for prescription drugs and later in some vapor-vacuum sealed caps for foods. Today it is most commonly used for beverages. In this process, an unthreaded aluminum cup is placed over the finish of a bottle. A pressure head forces the cap liner down against the mouth of the container while, at the same time, rollers press against the skirt of the cap, forcing the thin metal into the grooves and following the path of the container threads. Sometimes the bottom edge is also pressed under a locking ring that is part of the bottle finish.

Plastic closures began appearing in the early twenties on toothpaste tubes, but it was not until Bakelite phenolic became available at a reasonable price around 1927 that they came into general use. More expensive than metal caps, plastic closures initially were chosen mostly for luxury items. However, in recent years, improved resins and molding techniques have decreased costs and expanded the potential to add desired functions such as dispensing and tamper evidence.

Plastic caps provide an opportunity to create a so-called linerless cap, which can be up to 20 percent less expensive because no liner is needed. Usually made of PP to take advantage of its "living hinge" properties, these designs have a molded-in leaf or ribbed structure that seals against the container finish and serves as a liner. A circular flange in the cap base flares upward at an angle at its outer edge to form a spring that contacts the finish of the container and is compressed by torquing the closure to form a tight seal (see Figure 13.1). Since contact between closure and bottle must be leaktight, a good quality bottle finish is extremely important and tolerances must be tightly controlled.

Linerless closures are used for beverages and other products, particularly for dispensing applications where a liner would have to be removed before use. There are five basic designs: crabs claw, plug (valve) seal, land (flat) seal, v-seal and modified plug seal.

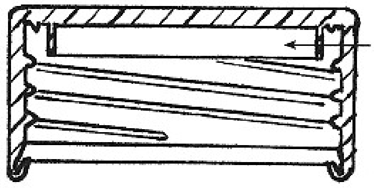

Figure 13.1.
Small protrusion eliminates the need for a liner on this CT design.

Plastic closures have come to be very popular with consumers, especially when teamed with plastic containers. As a result, plastic has become the preferred closure material and usage has been growing at a rate of 4.4 percent per year to reach an estimated 52.3 billion units in 1995 as opposed to a growth rate of 0.1 percent for metal closures which totalled about 33.8 billion units [1]. The total value for closures in 1995 was $2.2 billion.

Of all closures, beverages used 38 percent; food, 22.3 percent; alcoholic beverages, 18.7 percent; toiletries and cosmetics, 8 percent; drugs and pharmaceuticals, 6 percent; household chemicals, 3.7 percent; and automotive products, 3.3 percent.

As for the types of closures that make up this field, continuous-thread (CT) models make up 68 percent of the volume, of which 47 percent are of the breakaway band type, which provide tamper evidence. Dispensing closures are 12 percent, snap-type caps are 10 percent, child-resistant (CR) types take 5 percent, breakaway band milk closures 2 percent, and all other types, 3 percent [2].

Screw Caps

The largest body of caps, those containing threads, are of an almost endless variety. For one reason, the closure industry has not standardized on dimensions to the extent of the glass industry. The attitude has been that they will make caps to suit the containers, whatever they may be. This is due in part to the variety of materials that are used. Threads that are rolled into a metal shell cannot be characterized the same way as those that are compression-molded of a thermosetting plastic or of more flexible injection-molded thermoplastic materials. Furthermore, the caps from one supplier cannot always be interchanged with those from another source. This can be a nuisance, and for this reason, there is some advantage in buying both containers and closures from the same supplier, when this is possible.

Although U.S. packagers specify most dimensions and tolerances in inches, an early metal closure developed in France established a precedent for metric measurements that continues today (see Crowns, page 443). The size and type of thread are designated by the diameter in millimeters, coupled with a number that signifies the style, such as deep, shallow, or interrupted thread. Thus 22–400 means 22 mm in diameter with a shallow continuous thread. Caps for narrow-mouth containers should be made about 0.016 in. (0.4 mm) larger than the mean dimensions of the containers, with tolerances of ±0.005 in. (0.13 mm) for a good fit with a minimum of trouble. Important closure dimensions are shown in Figure 13.2. Container dimensions may be found in Table 8.6 in Chapter 8, Plastics.

The outside diameter of a metal screw cap measured near the top is the approximate nominal size. The metal cap manufacturer finds it easier to make a thread profile which has generous curves, so as not to fracture the metal as it is stretched and rolled into shape. Because of the wide tolerance in the dimensions of the bottles and the variations in the caps, as well, there is a very sloppy fit between the two parts in machine-shop terms and practices. The area of contact and the angle of forces are far from ideal, but for a hard cap on a rigid bottle are satisfactory in most cases. However, tight tolerances are demanded in packaging for ethical drug products and research

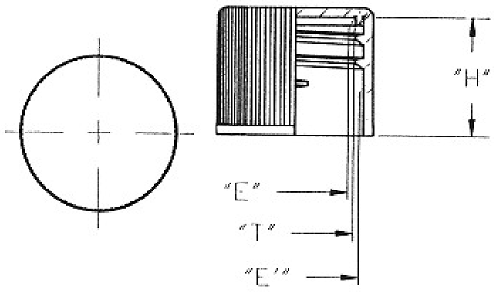

Figure 13.2.
Critical closure dimensions include the T dimension (inner diameter including the thread), the E dimension (inner diameter excluding the thread), the H dimension (the vertical distance between the inside top and bottom, excluding liner wells and other sealing elements). (From Journal of Packaging Technology, August 1987, p. 122. Author: Randall House. Reprinted with permission.)

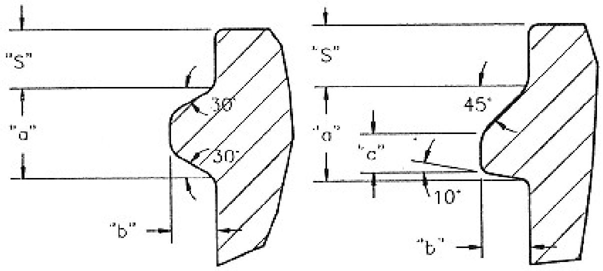

Figure 13.3.
L-style threads (left) were developed for glass containers but are less than ideal for plastic bottles, hence the development of the modified buttress M-style with a thread profile more compatible with the plastic container's greater flexibility. (From Journal of Packaging Technology, August 1987, p. 122. Author: Randall House. Reprinted with permission.)

continues on ways to test and improve seal integrity. Also, the design of dispenser closures has become very complex, requiring expert construction of the high-cavitation tooling and a strong knowledge of plastic properties on the part of mold makers.

For glass bottles, it is difficult to press molten glass into sharp corners, and any sharp change in profile causes stress concentrations that weaken the container. Thus, an "L-style" thread contour has evolved that consists of very large radii that blend into one another (see Figure 13.3). This may not be ideal from a purely mechanical standpoint, but it permits a high production rate and is generally adequate for the purpose.

With plastics, glass thread contours have been found to be less than satisfactory, because the softer plastics tend to jump the threads, or lose holding power in storage and shipment. Therefore, a "modified buttress" or "M-style" thread generally is used for plastic containers because it permits the closure threads to maintain a tighter grip (see Figure 13.3).

The security of a closure depends upon a number of things, such as the resiliency of the liner and the flatness of the sealing surface on the container. But more than anything else, security depends upon the tightness of the torque with which the closure is applied. The capping machine should be adjusted so that the chuck releases at the proper time. A torque wrench can be used to set the tension on the clutch. The actual application force will be a little bit higher than this, owing to the inertia of the machine working at high speed (see Table 13.1).

TABLE 13.1. Suggested Cap Application Torques.

Cap Size (mm)	Torque (lb in.)
15	6-9
18	7-11
20	8-12
22	9-13
24	10-15
28	11-17
33	13-20
38	15-23
43	17-26
48	19-29
53	21-32
58	23-35
63	25-38
70	28-42
83	34-49
89	36-53
100	40-60
110	45-65
120	48-72

Source: Pano Cap Canada Ltd., Kitchener, Ontario, used with permission.

The only practical way to check the tightness is to measure the removal torque. This should be done at a specified time after application, usually 5 min. Less time will not give a true reading and a longer time will allow more unusable material to be produced if the capping machine is out of adjustment.

It is also wise to check the torque again after several days to see whether there is any buildup or drop-off. Some liner materials, notably vinyls, seize upon the surface of the container after standing for a period of time and give a higher reading. In other cases, polyolefins will cold-flow so that there is a relaxation of tension on the sealing surface.

Adjustments in application torque should be made accordingly, since too high a figure will make it difficult for the consumer to remove the cap and, at the other extreme, there is the risk of leakage during shipment. Elevated temperatures also cause a loss of torque due to the expansion of the cap. This varies with the thermal properties of the material, but torque can be as much as one-third less at 120 F (49 C) for polyolefin caps.

It is also worth noting that plastics which absorb moisture, such as the filled thermosetting resins, may lose as much as half of their holding power if stored under humid conditions after being applied to bottles. Every effort should be made to keep product off of the threads when filling, too, as this may act either as a lubricant or as an adhesive depending upon its nature.

In the design of caps, depressed surfaces on the top should be avoided because they catch dust. In closures for wide-mouth jars, a raised section on the periphery that fits into a recess in the bottom periphery of the jar is sometimes provided to stabilize stacking on a dealer's shelf. The threads show on the outside of most metal caps, but there are some patented designs in which the metal is turned up inside to form the thread, leaving the outside straight and smooth.

Plastic caps made of thermosetting resins do not reveal the threads on the outside. However, thermoplastic materials sometimes will show the thread as a sink mark, caused by the shrinkage of the plastic in the mold. To camouflage this, it is common practice to put a fluted or knurled design around the sides of the cap. A slight doming of the top usually improves the appearance, as well.

The bottom edge of the cap should come as close to the surface of the glass as tolerances will allow, for the best cosmetic appearance. A generous radius on the inside of the bottom edge will more nearly conform to the shape of the container and avoid touching at that point. The cap liner should preferably be snapped in place instead of glued so that it can rotate inside the cap, thereby reducing friction when the cap is being tightened or loosened. This is easily done in a molded closure, but more difficult with a metal cap.

In selecting materials for caps, the effect upon the flavor or odor of the product may be a factor. Thermoplastics generally are better than thermosets in this case. Product compatibility is another important consideration and in testing for it, simply immersing the closure in the product for a period of time is not enough. When a cap is screwed onto a container, it is under stress, and it is in this condition that the product may cause cracking, which would not show up in a simple immersion test.

TABLE 13.2. Approximate Costs of Selected Screw Caps ($/1,000).

Size (mm)	Metal	PP	Phenolic	Urea
33	5.86	4.54	10.87	
43	6.52	5.44	13.04	20.32
53	7.28	6.24	14.56	23.25

Of course, the cost of a closure is also a selection factor. Approximate costs for a sampling of screw closures is shown in Table 13.2.

Lug Caps

The quick-acting lug style of cap is found primarily in the food field, where it is well known for its use on wide-mouth jars for baby food, salsa, pickles and applesauce (see Figure 13.4). It is also used on small-mouth bottles for catsup, juices and ready-to-drink teas, too. It has several advantages over the CT style. For one thing, it is simple for the consumer to remove with a quarter turn. Another advantage is that the pressure of the cap is more uniform around the sealing surface of the container. Particularly with containers of larger size, a CT cap is only pulling down about three-quarters of the way around, and there is no thread contact the rest of the way.

In the past, there has been some difficulty in getting a good match between the lug cap and the glass finish. As molds wear and the glass surface grows, the fit becomes tighter. This objection has been overcome to a large extent by a change in the design of the quarter-turn thread. Whereas previously the helix angle changed to a flat section at the bottom and the distance from the lug surface to this flat portion (L dimension) was very critical, now the helix angle is carried all the way down. This makes it self-adjusting, and the seal depends on the amount of torque applied and not on the L dimension to the flat.

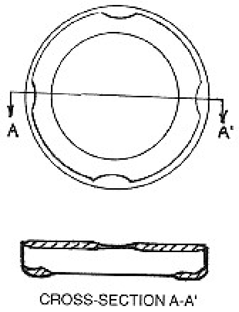

Figure 13.4.
Lug closure, mostly used for food packaging, has a flowed-in gasket to seal against glass finishes. The quick-turn cap gives an instantaneous and strong seal.

Crowns

The crown cap was invented by William Painter of Baltimore, who was granted a patent in 1892 and whose statement that his new closure "gives a crowning effect to the bottle" established this closure name. The Crown Cork &Seal Company, Philadelphia, was formed to manufacture these caps.

The Phoenix cap, a flat disk with a separate split ring to draw it down tight, is interesting because its various sizes were designated in millimeters. In 1892 Achille Weissenthanner developed this cap in Paris. It was shown at the Columbian Exposition in Chicago the following year in four sizes: 48, 53, 58, and 63 mm.

Originally the liners for crowns were cut from solid cork, but in 1912 composition cork was introduced for this purpose. "Spot crowns," consisting of disks of paper, foil, or film centered on the cork liner, were added to better preserve the sensitive flavors of ginger ale, orange soda, and beer.

In the United States, even composition cork has largely disappeared to be replaced by such plastics as low-density polyethylene (LDPE), ethylene vinyl acetate (EVA), polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), and polyethylene terephthalate (PET). These can be used alone or in combination with aluminum foil, pulp, chipboard, or newsprint and with waxes and adhesives that bond the materials together in various combinations. Another lining option is a coextruded film/foamed plastic/film structure made from homopolymers and copolymers.

In 1966, a twist-off crown closure was developed as a replacement for conventional crown closures, which require a tool to open. Since they can be removed easily by hand without a bottle opener, they are preferred by most consumers. Many beers use the twist-off design. Soft drinks have almost totally replaced crown closures with either aluminum "roll-on" closures or CT plastic closures (see Screw Caps, page 437), which are tamper evident and reclosable.

Dispensing Caps

There are many types of closures that add convenience and utility to product dispensing. Dispensing closures are a rapidly growing segment and include basic one-piece hinged flip tops (see Figure 13.5) and two-piece discs, turrets, pull-push spouts and twist-open/twist-close designs, plus even more complex faucet-like spigots to empty large containers, sprayers, pumps, and a wide variety of specialized applicators. (Note: See Chapter 11, Pressurized Packaging for information on sprayers and pumps.)

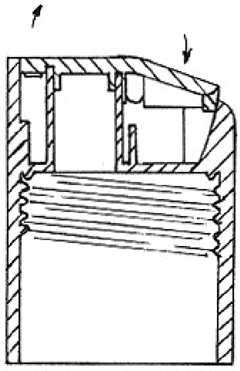

Figure 13.5.
Screw-on flip-top closure for viscous liquids dispenses by flipping up the hinged lid and squeezing the plastic bottle.

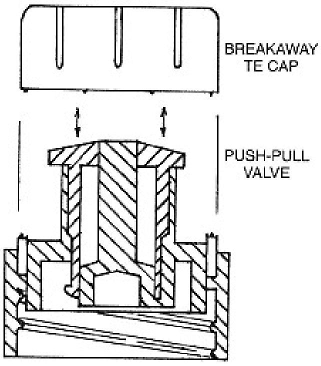

Figure 13.6.
Push-pull "sport" cap for drink and water bottles is linerless and features a breakable tamper-evident band.

Two-piece disc styles can be made in two different colors and operate with one hand by pressing one side. Common applications include shampoo and other personal-care products. Turret, or toggle, styles also are common on personal-care products and feature a spout that must be lifted to open and pour.

As the name implies pull-push spouts, or sport caps, pull up to open and are pushed down to close (see Figure 13.6). Long a fixture on dishwashing liquids, these closures now are gaining favor for beverages, particularly isotonics and water. More likely to be found on mustard or glue containers are the mechanical twist-open/twist-close styles.

Other dispensing options include shaker closures fitted with solid liners that seal the bottle but can be removed by the customer for dispensing; sifter tops for powders and granular products, such as ground spices (see Figure 13.7); cut-off snip caps with a friction-fit reclosure device; and roll-on fitment/closure combinations.

Best known as an applicator for deodorant and antiperspirant lotions, the roll-on dispenser is a very effective applicator for such products. One of the earliest patents for this type of package was issued to Ralph H. Whitney of Owens-Illinois in 1958. The balls are made of polystyrene, polypropylene

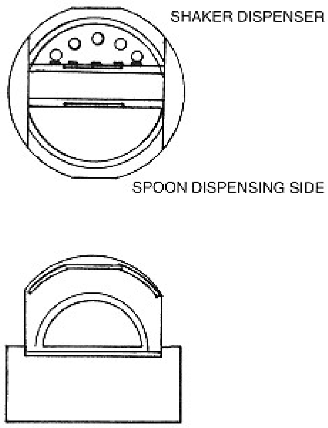

Figure 13.7.
A cap that permits sifting and spoon dispensing is closed with two pivoted and hinged covers. This screw cap is for dry powders and flakes, mostly foods.

(PP) and PE in sizes ranging from 3/8 to 1.5 in. (9.5 to 38.1 mm) in diameter with a 1-in. (25.4-mm) ball being most popular. The largest balls are relatively dense and tend to make the package top-heavy. For this reason, some manufacturers specify hollow balls in the larger sizes. While glass containers once were common, virtually all roll-ons now use plastic bottles. Regardless of the container, a soft plastic retainer is necessary to ensure a tight seal when the ball is forced down by the screw cap.

In the applicator arena, caps with a boss on the inside can hold a brush or a glass rod, or sometimes a sponge and are used with cosmetics, cleaners, polishes, and adhesives. PE rods with the cap liner molded as an integral part are made to be used with standard caps for dispensing droplets. Caps with a center hole are available for use with medicine droppers.

Special Function

In addition to dispensing, closures often are called upon to provide other functions. One design that incorporates an oxygen scavenger in the resin removes shelf-life-sapping oxygen from the product itself and the headspace throughout the storage period.

More common special functions add child resistance, tamper evidence, and/or compliance assistance.

Child-Resistant Caps

The Poison Prevention Packaging Act of 1970 stipulates that hazardous household products should have child-resistant (CR) closures that 80 percent of children 3-1/2 to 4 years old cannot open, but 90 percent of adults can use successfully Products that must use what is termed “special” packaging and the test protocols to determine compliance are specified by the Consumer Product Safety Commission (CPSC) (see Chapter 20, Laws and Regulations for more information). A list of products requiring CR closures is shown in Table 13.3. Currently, ammonia and petroleum distillates (as individual products) are being considered for addition to the list.

As a result of complaints from senior citizens that the existing CR closures were too difficult to open and reclose, a fact substantiated by a CPSC consumer study, new regulations were approved in 1995 that re-emphasized the importance of ease of use for senior adults [3].

Under the new Senior Adult Use Effectiveness (SAUE) test protocol, an older adult panel of 100 people between 50 and 70 years of age is divided into three age groups; 50 to 54, 55 to 59, and 60 to 70. The groups together

TABLE 13.3. Products Requiring Child-Resistant Closures.

Antihistamine/sleep aids containing diphenhydramine
Aspirin
Aspirin substitutes containing acetaminophen
Cough syrup with codeine (a controlled drug)
Glue and artificial fingernail removers containing acetonitrile
Ibuprofen
Iron-containing medicines
Iron-containing vitamins
Loperamide (anti-diarrhea medicine)
Mildewcides
Naproxen
Oil of wintergreen (methyl salicylate)
Oral prescription medicines
Over-the-counter (OTC) preparations containing lidocaine and/or dibucaine (anesthetic medicines)
Permanent hair wave neutralizers containing sodium or potassium bromate
Toilet bowl cleaners
Mouthwashes containing 3 g or more of ethanol (alcohol)
Ant and roach baits
Drain cleaners containing sodium or potassium hydroxide or sulfuric acid
Furniture polishes containing petroleum distillates
Oven cleaners containing sodium or potassium hydroxide
Antifreezes containing ethylene glycol
Charcoal lighter fluids containing petroleum distillates
Gas-line antifreezes containing methyl alcohol
Lawn and garden pesticides
Paint thinners containing petroleum distillates
Pool chemicals
Turpentine
Windshield washer liquids containing methyl alcohol

Source: U.S. Consumer Product Safety Commission, Washington, D.C.

all must have 70 percent females. There are two test periods. The first for 5 min determines whether they can successfully open the test package; in the second one, the testers demonstrate whether they can open and reclose the container within 1 min. If unsuccessful, panelists are tested on a non-CR cap to judge their manual dexterity. If not able to manipulate it, the panelist is rejected from the sampling.

Consumer-packaged pesticide products regulated by the Environmental Protection Agency (EPA) also follow the new protocols, except that EPA will use the original 18–to 45-year-old adult panels. Products packaged in metal cans or aerosols are exempt from the SAUE requirement and will continue to be judged only by 18–to 45-year-old panelists.

The children's panels, up to four groups of 50 each per test container, between the ages of 42 and 51 months, as before, will now be divided into three age categories instead of the original ten. A first group of 50 children will determine a pass/continue/fail situation. Then, additional panels of 50 children can tackle closures that fall into the "continue" category up to a total of 200 to meet the required percentages of inability to open a test container. The requirement is still that 85 percent must be unable to open the container before demonstration, 80 percent after a demonstration.

Only Canada, the United Kingdom, Germany, and The Netherlands had CR laws until 1992 when the European Economic Community adopted the International Standards Organization (ISO) standard 8317 as its CR packaging regulation. Designated EN28317, this rule has both similarities and dissimilarities to the U.S. law.

CR packaging is a vast and growing business, currently composed of five main classes: snap, CT, and lug-style caps; strip packaging in plastic/foil thermoforms; and aerosol overcaps. There are many variations within each category, but most require two dissimilar actions to access the contents of the package.

With CR closures, the user must find a tab or latch or rotate the cap to a predetermined position before it can be removed (see Figure 13.8). Today, there is a trend toward one-piece, constructions and features such as large thumb snaps to make opening easier.

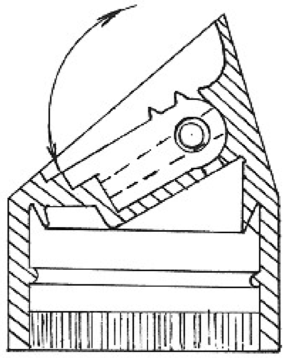

Figure 13.8.
CR dispensing closure is configured to apply strong chemicals to bathroom fixtures, especially under the rims of toilet bowls. Finger operation of a flip nozzle is graded acceptable by the CPSC. The cap features snap-on application and a linerless seal.

Over the years of tests, certain observations have been made about CR packaging. Closures tend to perform better on plastic and metal containers than on glass. Smaller closures are easier for children to master than large closures. Identical closures on bottles of the same design but different size will test differently. The type of closure liner also influences test performance.

CR closures generally fall into four types: the veteran palm-and-turn, align-the-arrows, squeeze-and-turn, and latch-top. Palm-rotatable closures that also require downward pressure have been improved by requiring less downward force to activate. The same goes for squeeze-and-turn designs.

Aligning the arrows on containers and snap caps has always been easy, but snapping the lid off is another story. It is now easier through use of larger unlatching mechanisms. The same goes for the captive cap and latching mechanisms.

Tamper-Evident Caps

Closures that resist tampering with products entered the picture in 1982 after seven people in Chicago died after taking Tylenol capsules that had been refilled with cyanide and replaced on the store shelves. This tamperer has never been identified.

But McNeil Consumer Products, Fort Washington, Pennsylvania (the maker of Tylenol), and the Food and Drug Administration (FDA), Washington, D.C., with incredible speed, emptied the nation's stores of the product and introduced regulations requiring all over-the-counter (OTC) drugs to include a tamper-evident (TE) packaging device or devices that would visibly indicate if a container had been opened. A package statement that draws consumer attention to such a TE device also is required. Ethical (prescription) drugs were exempted from this regulation because they normally pass directly from a pharmacist or physician to the consumer.

After subsequent tampering incidents and deaths, FDA amended the regulations to require two TE devices for capsule products, one of which may be sealing of the capsule itself. In fact, many OTC drugs have adopted more than a single device voluntarily and food products, which have been involved in terror-tampering attempts for many years, but were not included in the drug regulations, are steadily adding TE devices to their packaging. A problem that slows such adoption is that profit margins on most processed foods are traditionally low and many TE devices are designed for the higher margin drug products. Another hangup is a fear by food packers that consumers will adversely react to package statements calling attention to a TE device. As a result, many food companies use a “freshness seal” reminder instead of TE warning.

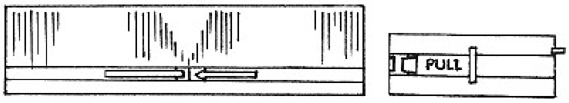

Figure 13.9.
Snap-on TE closures are available in small and large diameters in linerless (above) and lined styles. Opening is by pulling slightly different grooved tear strips.

Nevertheless there are a variety of TE closure options available. Typical designs are based on a breakaway band or tear strip (see Figure 13.9).

One early tamper-evident (TE) version developed by Albert Obrist Ltd., Switzerland, and licensed to National Can Co. (now American National Can Co., Chicago); Owens-Illinois Inc., Toledo, Ohio; Continental Group (now Continental Plastics, Inc., Triadelphia, West Virginia); and Portion Packaging Inc., Trevose, Pennsylvania, was claimed to be 20 percent less costly than aluminum roll-on styles. Made of PP, it had the appearance of a conventional screw cap, except for an extension of the skirt that is heat-shrunk to the bottle neck after the cap is torqued on. When the cap is removed, the bottom ring splits and comes off with the cap. Today there are many TE styles from which to choose.

Other popular TE devices include under-the-cap inner seals that are sealed to the bottle finish, tape-over seals that must be torn away, or shrink capsules or bands, some of which tuck under the bottle and over the cap and are tough and brittle after heat treatment. (More information on bands and seals may be found on page 458–460.)

Compliance Caps

Another problem with elder citizens (or not so elder, in fact) is neglecting to take their required medication or not taking the proper dosage. Studies have shown that as many as 50 percent of all prescriptions are not taken correctly, leading to over or under medication [4]. This has resulted in the development of compliance aids as a part of the packaging: instructions, labels, even such mechanical devices as counters to remind the patient when it is time for a dose.

Corks

The age-old use of cork as a stopper material is very justified. The material has a dense structure that is virtually impervious to penetration by oxygen or water. It is also elastic, compressible and low in thermal conductivity.

The bark of the cork oak *(Quercus suber)* from Spain and Portugal is still is used for stoppers, mainly for wine bottles, although plastics are gaining in popularity. When the cork tree is at least 12 years old, the first stripping of the bark takes place. The tree is not stripped again until 9 years later by decree of Portugal's Junta Nacional de Cortica. Cork suitable for wine stoppers is not obtained until the third harvest when the trees are at least 30 years old.

After air drying, the cork is taken to the factory to be boiled to destroy insects and molds and to shrink the cork pores. After rinsing and bleaching, the cork is sorted for quality. Some cork stoppers are decorated with embossed wood tops made on the same equipment that is used for making wooden checkers.

Wine corks generally are divided into three grades: second quality for wines that are aged a relatively short time; first quality for longer periods of aging; and extra-select quality for premium wines. The U.S. wine and liquor industry uses three types of stoppers: straight wine corks, chamfered whiskey corks, and champagne corks. Straight wine corks are either 1.5 in. (3.8 cm) long for tenth bottles or 1.75 in. (4.5 cm) long for fifth bottles.

A champagne cork is 48 mm long by 31 mm in diameter (1.9 by 1.2 in.). The lower half is squeezed to half its diameter and inserted into the bottle, and the upper mushroomed half is bonded with a wire hood, or muselet, to hold it in place. This closure is usually covered with a decorative foil capsule or wrap.

Traditionally, wraps and capsules were made from lead foil, but relatively new restrictions on the use of any lead element in food, beverage, or medical product packaging have led to its replacement with aluminum foil or shrink film.

With the supply of natural cork diminishing in quality and quantity and rising in cost, some attempts have been made to substitute plastic “corks” for the bark stoppers. Effective designs have been created with outer rectilinear grippers that are easy to open. A new generation made from EVA offers reduced extraction force, increased resiliency, and greater consistency of corking and uncorking action. However, natural cork is still favored by vintners because of tradition, and it is difficult to change long-standing customs in the wine industry.

Rubber Closures

Stoppers also may be made of rubber. The largest use of rubber stoppers is in chemicals and biologicals. Sleeve stoppers have a skirt which is molded upward from the solid plug portion. After the plug is inserted in a serum bottle, the skirt is pulled down around the mouth. Other types of rubber plugs have a thin section in the center for insertion of a hypodermic needle. These plugs are held in place with aluminum seals that are crimped under the lip of the bottle and have tear-off tabs.

Suppliers of rubber stoppers usually also make rubber bulbs for medicine droppers. These sometimes are made with a flange on the bottom. When inserted in a cap with a suitable hole and a glass or plastic pipette, a closure capable of dispensing drops results.

Rubber closures can be autoclaved and also are used for food containers, usually as a flowed-in gasket. Resistance to acids is good, but hydrocarbons and oils cause swelling, and eventually will dissolve the rubber, as will esters and ketones. A synthetic olefin rubber (SOR) is available in sheet form for liners and gaskets; it is less expensive than cured rubber, while retaining most of its advantages.

Cap Liners

A small, but very important, closure component is the liner. It must provide a tight seal, be compatible with the product, and not be a source of contamination. In many cases not enough attention has been paid to this essential element, and a great deal of spoilage and leakage has resulted.

Liners usually are made with a resilient backing plus a facing material. The facing must be carefully selected to provide the barrier properties required and withstand abrasion from the sealing surface when it is applied or removed. Sometimes a lubricant is put on the facing. The backing must be soft enough to take up any irregularities in the sealing surface of the container, yet elastic enough to recover some of its original shape when the cap is removed and replaced.

Typically, liners are glued into caps with a casein-latex adhesive, although polyolefin caps can be molded with an undercut so the liner merely snaps into place and is free to rotate, thereby providing a continuing and more effective seal.

Liners often rely on wax coatings. It has a twofold purpose. It provides an excellent barrier to water vapor and serves as a lubricant on the mouth of the container. It has good resistance to acids and alkalies, but should not be used with organic solvents. Pulpboard can be saturated with refined paraffin, which melts at 120 F (49 C), and then coated with about 0.007 in. (179 µm) of microcrystalline wax, which melts at 140 F (60 C). The water vapor transmission rate is around 0.01 g/100 in.^{2}/24 hr. A thin wax coating often is used on liner facings made of foil or film, too. It improves the barrier properties against moisture loss, lubricates the sealing surface and fills any pinholes, which might be present in the facing foil. However, if the coating is too thick, it may flake off under certain conditions.

Backing Materials

The resilient material, which makes up the bulk of the cap liner, can be various types of paperboard, cork, rubber, plastic, or silicone elastomer used alone, coated, or saturated.

Pulpboard

The most widely used backing for pharmaceuticals, toiletries, and cosmetics is white pulpboard. It is made from groundwood pulp with a small amount of sulfite pulp added for strength. and supplied in thicknesses of 0.020, 0.030, 0.035, 0.040, 0.045, 0.050, and 0.055 in. (0.51 to 1.4 mm). Most common is 0.035 in. (0.9 mm) when used with a facing, or 0.040 in. (1.02 mm) when used alone. Pulpboard compresses 4 to 5 percent with about 80 percent restitution on reclosing.

Newsboard

Newsboard is made of reprocessed newspapers or unprinted newspaper stock. It is furnished in thicknesses of 0.020, 0.035, 0.040, and 0.045 in. (0.51 to 1.14 mm). Newsboard compresses about 6 percent with 80 percent restitution.

Composition Cork

Composition cork is made from ground cork with a plasticized phenolicresin binder in a ratio of about 4:1. Animal glue, blood albumin, or gelatin sometimes is used as a binder, with aqueous glycerin as a solvent-humectantplasticizer. Cork is composed of tiny microscopic cells, about 200 million/in.^{2} (3.2 billion/cm^3) Cork has considerably more compression than the paperboard materials mentioned above, and recovery also is quite good. It is coatable but cannot be wax-saturated. Cork comes in thicknesses of 0.005, 0.063, 0.083, 0.094 and 0.125 in. (0.13 to 3.18 mm). Fragrances and flavors may be affected if the cork is not covered with an impermeable facing.

Quality White Waxed Paper

Clay-coated sulfite paper is coated on both sides with 0.002 in. (51 µm) of refined paraffin wax with a melting point of 135 F (57.2 C). It generally is used with dry products. The water vapor transmission rate is 0.01 g/100 in. ^{2}/24 hr. It has fair resistance to weak acids, weak alkalies, and water, but is not recommended for organic solvents.

Facing Materials

The most critical part of the closure and, for that matter the entire package, is the facing material and construction. This disk is the key to package integrity. In the early days there were not many facings to choose from. In the late 1920s, the list was limited to tin foil, kraft oil, black oil, quality white waxed paper, and waxed pulpboard. The mainstay for food products was kraft oil, either plain or waxed. The biggest problems were in the cosmetic, drug, and chemical products. Vinylite and Pliofilm were introduced in the late 1930s and filled a long-felt need. These were followed by PVDC and then by PEs and other resins so that, today, we now have materials to suit almost any packaging situation.

Kraft Oil

Kraft oil, also known as Yellow Oil, is a supercalendered 0.004-in. (102-μm) kraft paper coated with about 0.0001 in. (2.6 μm) of oleoresin varnish on one or both sides. When the varnish is mahogany-colored, it is termed a dark brown acid-resisting facing.

Black Alkali-Resistant

Black alkali-resistant is a special alkali-resistant varnish that is colored black. It can be put on any of the papers that are used for kraft oil, but usually is made with supercalendered 0.004-in. (102-μm) kraft paper. Varnished papers have good chemical resistance to water, oils and greases, weak acids, and weak alkalies. They are not resistant to alcohols, hydrocarbons, chlorinated hydrocarbons, ketones, or ethers. The water vapor transmission rate is about 0.4 g/100 in.^{2}24 hr.

Casein-Coated Varnish Paper

All of the previously mentioned varnished papers can be casein-coated to provide additional resistance to organic solvents or to products that contain these solvents. This coating has excellent resistance to hydrocarbons, chlorinated hydrocarbons, ketones, esters, ethers, and absolute alcohol, but not 95 percent alcohol. The coating should not be used for products containing water. The water vapor transmission rate is about 8 to 9 g/100 in.^{2}24 hr.

Polyvinyl Chloride

PVC generally is supplied as a white-pigmented coating, which is calendered onto a white sulfite paper in a thickness of about 0.002 in. (51 μm). It has good resistance to oils and greases, water, alcohol, and petroleum solvents. It is resistant to acids and alkalies, except some oxidizing acids. Oxidizing and reducing agents generally have no effect, nor does chlorine. It is attacked by aromatic hydrocarbons, halogenated hydrocarbons, ketones, aldehydes, esters, aromatic ethers, anhydrides, and molecules containing nitrogen, sulfur, or phosphorus. The water vapor transmission rate is about 2 g/100 in.^{2}/24 hr. A “flash-waxed” coating will reduce this to about 0.5 g/100 in.^{2}/24 hr.

Foamed vinyl plastisols are being used for flowed-in gaskets and also as a substitute for cork in crown caps. They provide an excellent seal for carbonated beverages. Moisture loss and compatibility of foamed vinyl are about the same as those listed for PVC.

Solvent-Resistant Paper

A coating of clear or white urea-formaldehyde-melamine resin is applied to white, kraft, or drab express paper to produce this facing. It has excellent resistance to oils and greases, weak alkalies, alcohols, hydrocarbons, and ketones. It is not recommended for acids or chlorinated hydrocarbons. Heat resistance is excellent, but it is not as flexible as some of the other facing materials. The water vapor transmission rate is about 0.4 g/100 in.^{2}/24 hr.

Polyethylene

White sulfite paper is coated with 0.002-in. (51-μm) of high-density polyethylene (HDPE) or LDPE or laminated to a 0.002– to 0.010-in. (51– to 256–μm) film. Most solvents will not attack PE, and it is unaffected by strong acids and alkalies. Oil and grease resistance is generally good, but there are some exceptions, and tests should be conducted with the particular product to be packaged. PE is not a good gas barrier and should not be used for oxygen-sensitive products. Moisture protection is good, and the water vapor transmission rate is about 0.4 g/100 in.^{2}/24 hr for the 0.002-in. (51-μm) thickness. Heavier films test even better.

Polyvinylidene Chloride

White sulfite paper with a 0.001-in. (25.6-μm) coating of PVDC or a lamination of clear or white 75-gauge (0.00075-in., 19-μm) film is in wide usage because of its excellent barrier properties. The water vapor transmission rate is 0.4 g/100 in.^{2}24 hr and the gas transmission rate is likewise very low. It is resistant to weak acids, weak alkalies, oils, and greases. It should not be used with hydrocarbons, ketones, or ammonium compounds. It is suitable for hot packing of foods.

Polyester

Polyester film in various thicknesses is laminated to a white sulfate paper. Available in gauges from 35 to 100 (0.00035 to 0.001 in., 9 to 25 μm), it has good resistance to alkalies, alcohols, hydrocarbons, chlorinated hydrocarbons, ketones, esters, cellosolves, oils, and greases. It should not be used with acids, phenols, cresols, or benzyl alcohol. The water vapor transmission rate for a 50-gauge (13-μm) film is 2.5 g/100 in.^{2}24 hr.

Cellophane

Various types of cellophane are used as liner materials and also as TE seals, which are adhered to the mouth of the container. Plain transparent (PT) cellophane is made of regenerated cellulose. When used alone, it has poor moisture and water barrier properties. It does, however, have good resistance to absolute alcohol, hydrocarbons, chlorinated hydrocarbons, ketones, esters, essential oils, mineral oils, and greases.

It is sometimes used as a double or triple laminate, with itself or with coated cellophanes. Single films come in thicknesses of Code 250, 0.0008 in..;Code 210, 0.0009 in.; Code 195, 0.0010 in.; and Code 140, 0.0014 in. (from 20 to 36 µm).

More often the "moistureproof sealable transparent" (MST) types of cellophane are used. Their properties depend on the coatings combined with them. The standard coating is nitrocellulose, but others are available, notably PVDC, which has good gas and moisture barrier properties (see Chapter 3, Films and Foils for more information on cellophane).

Tin Foil

A lamination of 0.0015 or 0.002 in. (38 to 51 µm) of tin foil with paper, or directly onto the backing, will provide excellent moisture protection. The water vapor transmission rate is generally regarded as zero. It has good resistance to hydrocarbons, chlorinated hydrocarbons, alcohol, ketones, esters, oils, greases, and water. It should not be used with acids or alkalies.

Aluminum Foil

Aluminum foil is available in thicknesses from 0.00035 in. (9 µm) and up and can be laminated to paper or to the backing material. Because aluminum is fairly stiff and hard, it is better to use one of the softer backing materials, such as feltboard or cork for cushioning It can be used with hydrocarbons, chlorinated hydrocarbons, oils, and greases. It is not recommended for aqueous products, acids, or alkalies.

Lead Foil

Lead foil is available in two types for cap liners. "Chemically pure" (CP) foil is 100 percent lead and "composition foil" has a coating of tin which is 0.5 to 1 percent of the total thickness. Lead foil is supplied in thicknesses of 0.002 to 0.010 in. (51 to 256 µm) It is laminated to paper or directly to the backing material. It has good resistance to solvents, but is affected by acids and alkalies. It cannot be used with foods, internal medication, or topical drug products.

Vinyl-Coated Foil

A lamination of 0.00035-in. (9-µm) aluminum foil on kraft paper with a thin vinyl coating, usually lightly waxed, is widely used for toiletries. It is satisfactory also for mayonnaise and similar food products. Its water vapor transmission rate is extremely low, and it is resistant to weak acids, weak alkalies, alcohol, oils, and water. It is not recommended for hydrocarbons, ketones, ethers, or essential oils.

Polyvinylidene-Chloride-Coated Foil

A thin coating of PVDC, usually waxed, backed up with 0.00035-in. (9-µm) aluminum foil on white sulfate paper is a good choice for cosmetics. The moisture loss is near zero, and resistance to oils is good. It should not be used with hydrocarbons, ketones, or ammonium compounds.

Film-Foam Liners

There have been several film/foam materials developed in recent years, and out of this has evolved an almost universal liner combining PE film with PE foam and other plastic materials.

In 1968 Joseph Dukess started experimenting with plastic laminates for cap liners, and by 1973 he had perfected a process for coextruding PE foam between two streams of PE film. This structure is now being produced by several companies under license from Tri-Seal International, Inc., Blauvelt, New York, some with film on both sides of the foam, others with film on one side only. A recent development is two such liners with an additional ethylene vinyl alcohol (EVOH)/nylon lamination or a lamination of EVA/EVOH/LLDPE, both of which in plastic closures are said to be highly resistant to gas permeation without the use of more-expensive foil (see Chapter 3, Films and Foils for the properties of these materials). So versatile are the foam liners that these materials have captured a large share of the cap liner market.

Cone Seals

Still another molded PE cap liner that is widely used is in the shape of an inverted, truncated cone. In the center is a post with a blind hole that fits over a stud molded in the cap. This stud prevents the liner from collapsing and ensures a wedge seal in the mouth of the bottle.

Vented Liners

Some liquid and even dry products release gases during storage because of changes in environment, temperature, or product. Conversely, other products react to inside gases such as oxygen to decrease the inside container pressure.

Such products, require special venting closures that stabilize the pressure inside the container. There are various designs for these caps, but most of them have two or three notches or irregularities in the edge of the liner backing, extending across and just beyond the sealing surface of the bottle. The liner facing will have several pinholes near the center, placed so that they will not coincide with the notches in the backing. This allows gases to pass out or in through the cap threads, or the cap shell may have a small hole that permits passage. With a foam-plastic liner, small holes can permit gas passage or a microporous film facing can be laminated over the holes in a foam liner, a more expensive solution. Linerless caps can position the microporous film over a small hole in the cap.

Inner Seals

Inner seals, which form a secondary closure of a bottle by means of a flexible disc adhered to the land (lip surface), have been used for a long time. Advantages include protection from leakage if caps loosen, tamper evidence, enhanced shelf life by reducing moisture and gas transmission rates, and compatibility with hot-packing to provide partial vacuum in the package. Inner seals also project a quality image for the product and can be printed with special instructions or promotional messages and/or tabbed for easy removal.

There are basically three kinds of inner seals: glued glassine, induction sealed, and pressure-sensitive. Packaging engineers can now choose from many combinations of materials.

Glassine

A wax-bonded lamination of glassine to pulpboard typically is used as a loose component with the basic cap liner. When adhesive is applied to the mouth of a bottle or jar after filling, and the cap is torqued into place, the liner adheres to the container, creating a tight seal that must be torn away to remove. The liner, which stays with the cap when it is removed, must have a facing suitable for resealing the container when the inner seal is removed. This also applies to induction-sealed and pressure-sensitive seals, described below. Since glassine has a poor resistance to many liquids, it is used only with dry products. But since the bond is strong, it is acceptable as a TE device.

Induction

Induction seals are created by passing a cap containing a multi-ply liner in which, typically, a heat-seal-coated aluminum foil is wax-bonded to the facing. The aluminum also may be permanently adhered to paperboard to create a stiffer seal. When a capped container with such a seal is passed through a high-energy electric field, the foil creates an interference within the high-frequency magnetic-induction field that produces heat, melting the wax and allowing the heat-seal-coated aluminum to bond to the bottle land.

The heating coil is made of copper tubing with water circulating through it for cooling. The coil is just large enough to fit over the cap without touching it and should be mounted parallel to the conveyor. Induction seals create a strong bond with the container and are acceptable as a tamper-evident device.

Pressure-Sensitive

Pressure-sensitive seals typically are made from polystyrene foam coated with a pressure-sensitive adhesive. As the cap is torqued onto the container, the adhesive bonds to the bottle land. Such structures provide a good and relatively inexpensive protective seal, but are not suitable for products containing oils, hydrocarbons, or solvents.

Container Seals

Supplementary seals often are applied to luxury products to dress them up or to provide extra protection against contamination or tampering. These include aluminum foil capsules, film stretch bands, and cellulosic and film shrink bands.

Shrink Bands

The shrinkable band can be a tube of wet cellulose, which shrinks to a tight fit on drying. Although not acceptable to FDA as a TE device, because they can be re-wetted, removed, and replaced without evidence of tampering, cellulose membranes still are used for other applications.

These bands are made from regenerated cellulose, in somewhat the same manner as cellophane. Wood pulp is dissolved in caustic soda and carbon bisulfide, along with plasticizers, humectants, and colorants. The viscose that is thus produced is extruded as tubing from a die of the proper size for a particular cap diameter, into an acid bath which causes it to coagulate. Special colors are possible, but difficult to control in going from the alkaline to acid medium in the process. Opaque white is safest.

The bands can be printed with instructions or a sales message in any color, except that the background color will affect the print color; for example, blue ink on a yellow background becomes green. Capsules may be used in place of bands, but are much higher in cost and seldom specified. Viscose capsules can be used as primary closures for dry products, for example, to cover the sifter top on a powder container. The material is a poor barrier for moisture, however, and its chemical resistance is similar to that of uncoated cellophane.

Viscose bands are stored in water with some glycerine and mold inhibitors added. Applied to the package wet, they shrink as they dry, like any cellulosic. Specifications for size are given in millimeters, diameter first and then the length. In the case of capsules, the length is measured from the bottom edge to the midpoint of the top surface. This is for the desired finished size and not the size of the wet band or capsule.

Bands made from oriented (stretched) film are accepted for TE packaging. Extruded as a tube or heat-sealed as a wrap, bands generally range from 0.002 to 0.004 in. (51.3 to 102.6 µm) thick and are made to slip easily over the cap and neck or sometimes the entire length of a bottle, jar, or canister. In the latter case, the band is generally extended partly across the top of the closure and the bottom of the container for greater security after shrinking.

Applied by hand or machine, bands often are used in conjunction with an inner seal on bottles (see page 458 for more details on inner seals). When wrapped packages are passed through a heated tunnel, the band shrinks in about 3 sec to form a tight, TE seal.

Such TE seals must have a distinctive feature like a printed logo that would be difficult to duplicate to qualify under FDA regulations related to over-the-counter (OTC) drug containers. In addition, information must be prominently printed on the container advising consumers not to buy the product unless the TE device is intact. Increasingly such protection also is being applied to foods, toiletries, cosmetics, and other products even though it is not required. (For further information, see Chapter 20, Laws and Regulations.)

Stretch Bands

Stretch bands, on the other hand, are made about 20 percent smaller than the package and mechanically stretched just before placement and return to their original size in an instant to make a tight fit on the package. These bands often are printed and double as a label for bottles as well as other types of rigid packages.

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Chapter 14—
Corrugated Fibreboard

History

The most common type of shipping container being used commercially today is the corrugated box. The first patents for making corrugated paper were recorded in England in 1856. In the United States the first patents were granted to A. L. Jones in 1871 for an unlined corrugated sheet for packing lamp chimneys and similar fragile objects.

The first user of a box made of double-lined corrugated board was a cereal manufacturer, which obtained acceptance in the official freight classification for this type of shipping container in 1903. By the end of World War I, about 20 percent of the boxes were corrugated or solid fibreboard, and 80 percent were of wood construction. By the end of World War II, these figures had reversed, and 80 percent of all shipments were being made in fibreboard boxes.

Now more than $17.3 billion worth of corrugated containers are being produced in about 770 plants in the United States. Many of these are sheet plants, which buy combined board from other plants and do only the printing and cutting.

The proper name for a fibre shipping container is "box," rather than "carton" or "case," although all three terms are commonly used to describe the same type of container.

Box Construction

The most frequently used style of box is the "regular slotted container," generally referred to as an RSC, in which all the flaps are the same width and the outer flaps meet in the center (see Figure 14.1). It is made from a single piece of fibreboard with a manufacturer's joint in one corner, which is either stapled, glued, or taped (see Figure 14.2), and is shipped flat to the user's plant. There are many other styles of boxes, which will be discussed later, but the RSC is the mainstay of the box business.

Standards of construction for the elements of fibreboard boxes date back to the early part of the century and were originally formulated by independent and regional associations of railroads. These were combined, however, in 1919 into Consolidated Freight Classification Rules recognized by all railroads. Since 1934 the most important rule for packagers has been Rule 41. It sets forth the minimum packaging requirements for classes of goods, and elements have been incorporated by the U.S. Department of Transportation

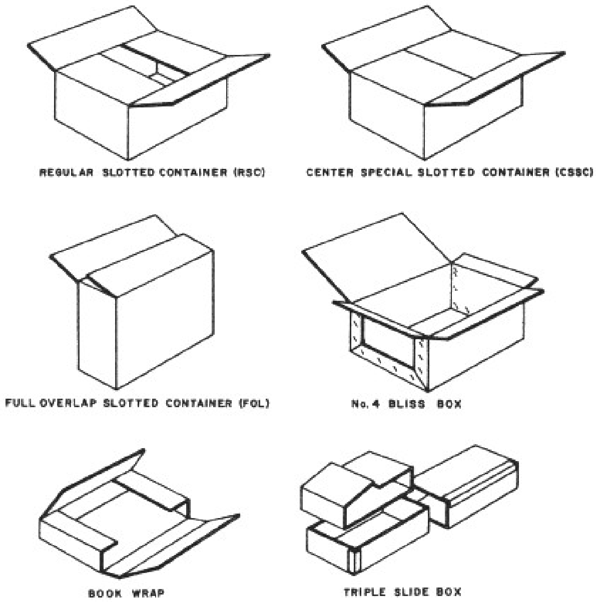

Figure 14.1.
There are many variations of these basic types of corrugated box styles.

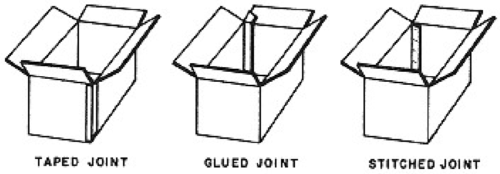

Figure 14.2.
The three main types manufacturer's of joints are shown. The glued joint can be made with or without the glue flap extending onto the top flap, and with the glue flap inside or outside of the box.

(DOT), Washington, D.C., into rules for the packaging of hazardous materials and also are recognized by most other carriers of packaged goods.

Since World War II, the motor freight carriers have steadily increased their percentage of the haulage business and in 1968 adopted Item 222, which is structurally like Rule 41, but has many individual differences. Today, the structure and performance of packaging for domestic transport is defined primarily by The Association of American Railroads, Washington, D.C., and the National Motor Freight Traffic Association, Alexandria, Virginia, except for the packaging of hazardous materials and wastes, which are regulated by DOT and the Environmental Protection Agency (EPA), Washington, D.C., respectively. For details on these regulations, see Chapter 20, Laws and Regulations.

Box Dimensions

The size of a corrugated box is always given in terms of inside dimensions and in the order of length, width, and depth. The length is the longest of the side panels, the width is the shortest of the side panels, and the depth is measured from open end to open end. Unless it is otherwise stated, the box maker will always assume that this is what is intended. Sometimes the direction of the corrugations is indicated by underlining the dimension that is parallel with it. Otherwise, it is assumed that the corrugations are vertical, that is, parallel to the depth dimension.

Scoring Allowance

When corrugated fibreboard is scored and folded at right angles, the center line of the sheet will intersect the score line; that is, half the thickness of the board will be on one side of the score line and half on the other (see Figure 14.3). Therefore, when the sheet is folded into a rectangle to form a box,

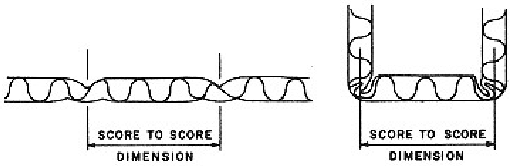

Figure 14.3.
Scoring allowances are based on the thickness of the corrugated board. For a given inside dimension, the scores should be one thickness farther apart. When the board is folded on the score lines, the scoring dimension falls in the center of the wall that is formed.

the inside dimensions will be less than the score-to-score dimensions by an amount equal to about one thickness of board. Likewise, the outside dimensions will be greater than the score-to-score dimensions by about one thickness of board.

Starting with the inside dimensions that are desired, the settings for the scoring wheels on the printer slotter can be calculated by adding a certain amount according to the thickness of the corrugated board being used (see Figure 14.4). If the result is an odd fraction in thirty-seconds or sixty-fourths of an in. (0.79 or 0.40 mm), it should be carried to the next higher sixteenth (1.59 mm) (except for such special cases as E-, F-, and N-flute boards), since box makers do not usually work closer than 1/16 in. (1.59 mm). It also should be noted at this point that the dimensional tolerance accepted in the trade

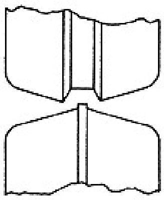

Figure 14.4.
The face or "point" on the bottom of the male scoring wheel makes a 0.0625-in.-wide (1.6-mm) score on the inside of the box. The space between the points of the female wheel is 0.3125 in. (7.9 mm), although this may vary for different grades of board. There are other styles of wheels, such as "five point" for double-wall board; single V against a flat wheel, sometimes used on printer-slotters; and double V, used on combiners. The type shown makes the strongest box when used for either vertical or horizontal scores.

for a finished box is ± 1/16 in. (1.59 mm). If specifications are written with closer tolerances, costs may be affected.

Allowances for horizontal scores are a little more complicated than for vertical. Since the small flaps go inside the large flaps in an RSC box, allowance is made for one top flap and one bottom flap thickness in addition to one thickness of board as before. Thus, the inside height is less than the score-to-score dimension by three thicknesses of board. For calculations, the thickness of the various types of board is given in Table 14.1. If the result is an odd fraction, it can be adjusted up or down to produce the desired fit. For good stacking with a dense load, it is usually better to work on the tight side.

The allowances given for slight variations in board thickness and bending vary from company to company. Therefore, it is more practical for an end user to provide a drawing of the panels and their required dimensions and let the box vendor work out the score allowances. Note on the drawing that "Score allowances have not been included" so the vendor designer will take care of it.

Board Construction

Corrugated fibreboard is basically made from two materials, a corrugated sheet of paper known as "medium" and one or two flat sheets of paper called "liners," or "facings." The latter are glued to one or both sides of the medium to create a "single-" or "double-faced" structure (see Figure 14.5). It is also possible to achieve "double-" or "triple-wall" board by alternating additional layers of medium and liner.

Corrugated medium is nearly always 9 points (0.009 in., 0.23 mm) thick and weighs 26 lb/1,000 ft^2 (127 g/m^2). However, the facings are varied in thickness according to the required strength. The corrugated medium may

TABLE 14.1. Rule 41-Grade Linerboard.

Weight		Caliper		Burst Resistance	
lb/1,000 ft^2	g/m^2	in	mm	lb/in.^{2}	kPa
26	130	0.008	0.203	70	480
33	165	0.010	0.254	85	586
38	190	0.011	0.279	92	634
42	210	0.013	0.330	100	690
69	345	0.020	0.508	135	931
90	450	0.023	0.584	160	1,103

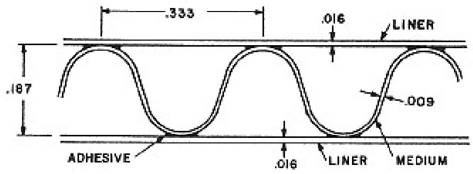

Figure 14.5.
A combiner puts liner(s) and medium together to produce corrugated board like this 200-test, A-flute structure.

be made of kraft, bogus, or semichemical fibre. (See Chapter 2, Paper and Paperboard for more information on these materials.)

Linerboards are generally fourdrinier or cylinder kraft or a filled sheet made from scrap paper called "jute," even though it doesn't contain any jute fibres. In 1949, about 28 percent of all linerboard was jute, and by 1959 less than 14 percent. There is also a shift from cylinder kraft toward fourdrinier kraft, so that the ratio is now about 40:1 in favor of the latter.

Cylinder kraft has more grain than fourdrinier, and therefore greater stiffness and tensile strength in the machine direction, but less in the cross direction (flute direction) than fourdrinier. The stiffness ratio of cylinder kraft linerboard is about 4:1 (machine direction versus cross direction), whereas fourdrinier kraft linerboard is said to be more balanced, with a ratio of approximately 2:1.

Liners

Most liners are made from natural kraft, a light brown material. However, more expensive bleached kraft is selected for special marketing purposes and has been used extensively in boxes for the pharmaceutical industry because of its "cleaner" appearance (which usually disappears during shipping). Mottled liners, a less white, less expensive material, appears to be replacing considerable quantities of the fully bleached.

The most widely used liner weighs 42 lb/1,000 ft^2 (205 g/m^2). Outer facings are usually the same weight, but occasionally can be "unbalanced" with different weights on each side. Unbalanced sheets have a tendency to warp and may be difficult to handle, either in the box maker's plant or at the point of assembly. For this reason, an unbalanced sheet should be avoided unless there is a very good reason for using it.

The main good reason is economics. A 200-lb-test board (90.7-kg) using the required two 42-lb/1,000 ft^2 (205-g/m^2) sheets may not be strong enough to protect a certain product, for example. But a 275-lb-test board (124.7-kg), requiring two 69-lb/1,000 ft^2 (337-g/m^2) sheets may be overly sturdy. In this case, an unbalanced structure using one 42-lb (205-g) sheet and a selected heavier sheet may be the answer.

Flutes

There are currently seven different flutings that can be applied to the medium. They are designated by a letter code with the most commonly used being A, B, and C. Five of the flutes have optional variations in the number of flutes per foot (see Table 14.2).

The larger the flute the wider the vertical column and, therefore, the greater the stacking strength in the vertical direction and the softer the cushioning in the horizontal direction. Hence, K- and A-flute boards are very stackable. However, when the flutes are concentrated closely together, as in B-flute board, there is a much greater resistance to crushing (note the flatcrush values in Table 14.3).

A-flute board is used as an economical and functional inner liner material for products of limited mass, which could otherwise collapse the flutes in horizontal impacts. B-flute board has more flutes per foot, a high flat-crush value, good end-to-end compression, and good inside dimensional control. It also has greater strength at the score lines. It often is used in small boxes because it folds neatly and makes a good-looking box. But its low caliper gives it poor vertical compression strength. In the 1940s, C-flute was created as a compromise to combine the best advantages of A and B flutes. It is now the

TABLE 14.2. Corrugations.

Flute	Medium Height, in.	Combined Height, in. (0.020-in. liners)	Number of Flutes/ft
K	0.260	0.280	39.4
A std.	0.177	0.197	35.4
A optional	0.158	0.178	37.7
C std.	0.142	0.162	39.4
C optional	0.140	0.160	38.6
B std.	0.098	0.118	46.9
B optional	0.097	0.117	46.9
E macro	0.053	0.073	84.7
E micro	0.044	0.064	89.9
F	0.030	0.050	128
N std.	0.020	0.040	170
N optional	0.020	0.040	140

TABLE14.3. Flat Crush Values.

Flute	Flat Crush psi
A	40
B	57
C	50
E	140

most popular board in boxes for transporting products of low to intermediate weight and up to moderate fragility.

K-flute is a special board used where superior stacking strength and lateral cushioning against side impacts is required. Boards with E-, F-, or N-flutes are more like paperboard, but with a great deal more lateral and vertical strength. E-flute board is used as a paperboard substitute in folding cartons and, increasingly, in inner box dividers and liners to separate product elements. It prints very well. F-flute is almost entirely used today in fast-food containers where its greater strength has enabled it to replace paperboard, and N-flute is a new structure that is striving for the same markets.

These special flutes are in somewhat limited supply and may not be readily available everywhere. While flute measurements for all corrugated boards are shown in Table 14.2, no data on the performance characteristics of K-, E-, F-, or N-flutes and their relationships to the more established flutes have as yet been documented by either corrugators or national testing bodies.

Despite the growth of C-flute boxes, it is unlikely that either A- or B-flute corrugators will be discarded. Board manufacturers need all of the flexibility they can get and the selection of the proper structure is a matter of prioritizing the greatest needs at the expense of lesser features, which are desirable but not essential. This is a reason why the thinner, optional board flutes available from some manufacturers in some of the above flutes exist. They are used where an incrementally better lateral strength is more important than stacking strength.

For heavier items, flexibility is attained by selecting double-wall constructions involving AB or BA or BC or CB flutes. Even E-flute is being considered as a double-wall or liner material. Unbalanced structures in which the inner, outer, and central liners in a multiwall structure are of different weights are more common, today, because these constructions can offset the bending of box walls under loading and lessen warpage if made properly. Where good exterior printing is required on combined board, it may be desirable to put the B-flute on the outside since it has a smoother surface and does not crush as easily under the pressure of printing.

Combining

The process of adhering the flat sheet known as the liner, regardless of which side it is on, to the corrugated sheet, which is called the medium, is termed *combining.* It is performed on a machine called a "combiner." Cutting and scoring wheels and a cut-off knife deliver sheets cut to the proper length and width with creases perpendicular to the corrugations. In the conventional RSC box, these creases are the horizontal scores that form the hinges for the top and bottom flaps. The vertical scores are made in a subsequent operation on a printer/slotter. Joining the peaks of the corrugations to the linerboard is done by an adhesive. A cold starch paste was used initially, but quickly gave way to sodium silicate, which, in turn, has been replaced by a mixture of starch, silicate, and clay, which gives better performance. Other adhesives may be used for special purposes (see the adhesive section in Chapter 12, Labeling and Decorating for further descriptions of adhesive types).

A combiner usually can be set up to make only two types of flutes, and as new plants are built, a decision must be made as to which two it should be. Most new equipment is being built to make B- and C-flute, and it is becoming a bit more difficult to find A-flute.

Manufacturer's Joint

The ends of the box blank can be joined in several ways, but both truckers and railroads have specific rules on how it is done. Take Rule 41, for example. The flap must be 1.25 in. (3.18 cm) in length and can be an extension of either the end or side panel and located either outside or inside this adjacent panel The flap may be secured to the adjacent panel by staples or stitches spaced 2.5 in. (6.4 cm) apart for boxes up to 140-lb (63.5-kg) gross weight and 1 in. (2.54 cm) apart for heavier box loads (see Figure 14.2).

The manufacturer's flap joint on boxes not exceeding 65-lb (29.5-kg) gross weight also may be closed with a 2-in. (5.1-cm) strip of tape not less than 60-lb/3,000 ft^2 (97.7-g/m^2) basis weight and having a burst strength of 60 psi (413.7 kPa). The tape may be reinforced with glass or other natural or synthetic fibres.

For boxes exceeding 65-lb (29.5-kg) gross, a 3-in. (7.62-cm) tape, composed of two or more firmly glued plies, not less than 150-lb/3000 ft^2 (244-g/m^2) basis weight and having a burst strength of 150 psi (1,034.3 kPa) must be used, although lesser basis weights are acceptable if the tape is reinforced with fibres. In both cases, the tapes must extend the entire length of the joint.

Boxes without a flap may also be taped together at the point where the end and side panels meet. In this case, the sealing strips must be of sufficient strength so that a rupture of the joint causes fibre failure of one or both panel facings.

Glued joints also are permitted. The adhesive must be water resistant and applied over the entire length of the manufacturer's joint flap.

Triple-wall corrugated boxes can be stapled or stitched in the 2-in. (5.1cm) joint flap if it is crush-rolled and flattened before fastening. With a 3-in. (7.62-cm) flap, triple-wall boxes can be glued at the die seam with a waterproof adhesive applied over the entire flap area and dried under pressure. Solid fibre boxes have similar rules for stitching, stapling, or gluing the manufacturer's joint.

Rule 222 varies a bit from the above in actual figures, but the procedures are similar.

From the standpoint of machinability in automatic casing operations, the stitched joint shown in Figure 14.2 can be a problem, since products may hang up on the top of the manufacturer's joint during loading. The glued manufacturer's joint that extends a short way onto the top end flap and the taped joint are satisfactory as are externally fastened manufacturer's joints.

Coatings

Various coatings can be applied to corrugated board to minimize abrasion against finished surfaces of appliances or furniture, or to impart waterproof or water-resistant properties. Other reasons for coating might be to improve the appearance, protect the printing, provide an easily cleaned surface, impart grease resistance, or improve mechanical strength under high-moisture conditions.

There are two widely used methods of applying coatings to corrugated, “curtain” and “cascade.” In curtain-coating equipment, flat blanks are passed through a continuous stream of a molten wax and plastic compound, which falls from an extrusion slot or weir in the top of the machine through an opening in the conveyor table into a reservoir where it is collected and recirculated through the system (see Figure 14.6). Moving along the conveyor at about 1,000 ft/min (305 m/min), the flat blanks, which have already been slotted, scored, and printed, pass through this falling curtain and receive a uniform coating on the top surface and over the edges. Maximum sheet size is about 5 by 7 ft (1.5 by 2.1 m). It is possible to restrict the coating to a strip and, save material if the design does not require coating all the way to the edge. However, under these circumstances, there is tendency for the coating to be heavier near the edges.

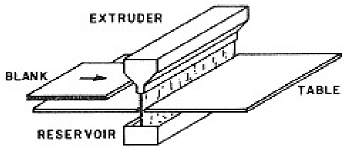

Figure 14.6.
In a curtain coater, a hot-melt blend of wax and plastic flows down from the extruder in a continuous sheet and is collected in the reservoir at the bottom, to be reheated and sent back up to the extruder. A box blank, passing from left to right through this curtain, receives a uniform coating on the top surface and over the edges to provide waterproofing.

Curtain coatings generally consist of about 60 percent paraffin with the remainder made up of microcrystalline waxes, ethylene-vinyl copolymers, and petroleum resins. The mix can be applied in a layer as thin as 0.001 in. (0.03 mm) or about 5 lb/1,000 ft^2 (24.4 kg/m^2) and can run up to 9 lb (44 g) for the heaviest requirements.

Coatings range in cost from about 45 cents to 58 cents/lb, depending on the type and amount required for the application. Utility coatings at the lowest cost and coating level generally are used on shippers for appliances, furniture, motor oil, and other noncritical applications. Coatings in the middle grade of cost and application poundage can carry produce and poultry over moderate transport distances. The heaviest premium coatings containing more of the expensive additives are reserved for produce, fish, meat, and poultry that are hydrocooled and/or shipped great distances.

Cascade coating, on the other hand, operates on fully made boxes that are in a knockdown state and flood coats the entire box, penetrating every panel of board with a hot compound that is mostly paraffin with about 2 percent of polymers and relatives of polyethylene. The coating is generally about 35 percent of the tare weight of the box. In other words, a 2-lb (0.9-kg) box after coating would have about 0.7 lb (0.3 kg) of wax in it. This so-called "dry" process, involves a blower to remove most of the surface wax, which then dries almost instantaneously. Cascade-coated boxes are used extensively—particularly on the West Coast—for shipment of produce, fish poultry, plants, and flowers.

Both coating techniques are decried by environmentalists because it is difficult to separate the wax from the paper fibre during recycling. However, both the paper industry and coating manufacturers are working on a solution since the coated boxes are economical and serve as a functional method for transporting many goods.

Design Considerations

The most economical box for a given cubic contents has the proportions 2:1:2; that is, the length is twice the width and the height is equal to the length. This requires the least amount of board to enclose a given amount of space using the RSC construction, and while it does not take into account the cost of material used for the manufacturer's joint, it is a satisfactory guide for all but the smallest boxes.

A container that is twice as long as it is wide has the further advantage of interlocking in a stack to form a more stable pile. Each box can be placed at right angles to the ones below it. The perfect cube has long been considered the poorest shape for warehousing because it cannot be interlocked. However, in the age of stretch and shrink wrapping for pallet loads, there is a place for column-stacked containers, including cubical boxes. Heavy loads will stay in place with properly gauged wrapping and lighter loads can be restrained by extending the film wraps over the edges of winged pallets to tie the load directly to the pallet or by using angled corner braces held in place by stretch wrapping. (See Chapter 15, Wood Containers for more information on pallet structures).

If a choice can be made in the arrangement of the contents, it is well to give some thought to the proportions of the box in terms of maximum utilization of space in storage and shipment. The width of conveyors, size of truck bodies and railcars, and pallet patterns all have some bearing on the design of an optimum box and the use of standard pallet sizes, such as the widely used 42-by-48-in. (106.7-by-121.9-cm) pallet. Ideally, the tier pattern should interlock the boxes with not more than a 1-in. (2.5-cm) overhang and with a minimum of open, waste space.

Within the boxes, products can be arranged tightly together or, in the case of some fragile and scratch-prone objects, with suitable cushioning or corrugated dividers such as shown in Figure 14.7. (See Chapter 16, Cushioning and particularly Figure 16.7 for more information on internal product protection).

Flute Selection

What flute is used in a corrugated structure depends upon the product content, particularly its fragility, density, and self-supporting characteristics. If top-to-bottom compressive resistance is important, as in the case of non-supporting products stacked to a great height in the warehouse, A-flute is the proper choice. Fragile articles also will receive better cushioning from A-flute fibreboard, except in cases of high density that may indicate a higher flat crush value (see Table 14.3).

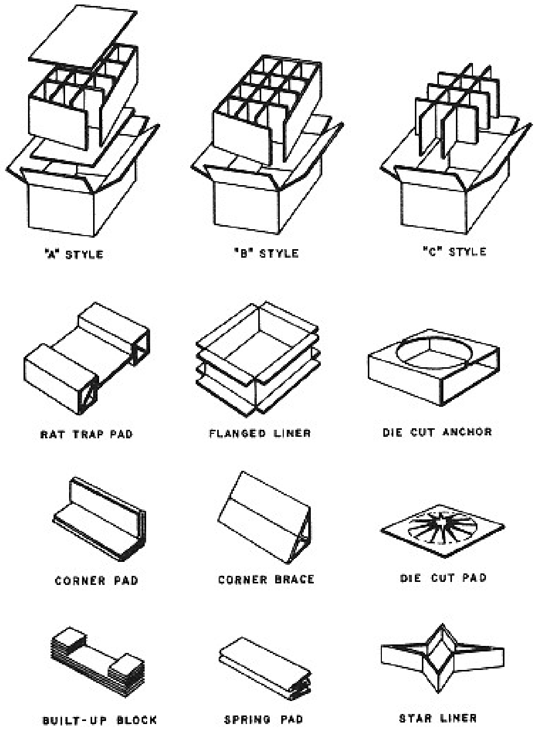

Figure 14.7.
Various types of pads, blocks, and braces are made of corrugated board to secure and cushion fragile items. The A, B, and C styles are partitions used in the glass industry for reshippers.

For greater crush resistance, B-flute, with more lines of contact between the corrugated medium and the facing, is a better choice. It also has greater strength at the score line, where canned foods have a tendency to tear out, and better end-to-end crush resistance. For very small boxes, B-flute folds more easily and makes a neater looking package.

A compromise between A and B, which is very popular, is C-flute construction. It offers reasonably good stacking strength and a fair amount of stiffness. A good choice for average types of loads, it is easy to source because of its widespread use.

For interior parts, A-flute is serviceable because of its greater thickness and better cushioning properties, but the density of the contents must be taken into account to prevent collapse of the corrugations under impact. Also, E-flute is now used for some interior partitioning and product support. It occupies less space and for products of low fragility can separate them and prevent scuffing.

Corrugation

Normally the direction of the corrugations in a box is vertical to provide maximum stacking strength. Interior corrugated parts generally position corrugations vertically also, although a liner sometimes will have the corrugations in the horizontal direction to withstand the shock from sliding down chutes and from being carried on conveyors or from humping in freight cars. Actually the difference in the strength of vertical and horizontal corrugations is not very great. The figures in Table 14.4 show that B-flute board actually has more stacking strength horizontally.

Printing

It is possible to print slotted boxes from rubber dies very economically in the same operation which makes the slots and vertical scores. The machine, which performs this operation, is known as a printer-slotter. While these generally apply one or two colors, some models can print four or more. It is also possible to print halftones and process colors on corrugated, but a long run is required to justify the complex setup. Also, finer printing is available by preprinting the outside liner sheet on standard printing presses and then combining it.

The printing dies for printer-slotters are made of fairly soft rubber. If the

TABLE 14.4. Stacking Strength of Horizontal Corrugations or Stacking on Side.

A-flute horizontal = 80 percent of A-flute vertical

B-flute horizontal = 120 percent of B-flute vertical

C-flute horizontal = 90 percent of C-flute vertical

te horizontal = 150 percent of E-flute vertical

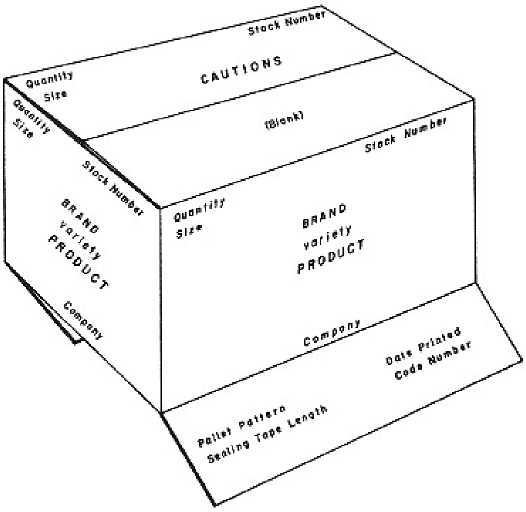

Figure 14.8.
Shipping containers should provide essential information on all sides, as well as the top. The extra cost is insignificant. The arrangement shown is based on surveys of preferred locations of quantity and size designations among wholesalers and retailers in the food and drug trades. One top flap is left blank for name and address of consignee and other shipping information.

rubber is too hard, it will crush the corrugations and weaken the box. Various typefaces are available, and logotypes or special designs may be engraved directly in the rubber or made up as woodcuts from which the rubber is molded. Since the printing dies are flexible and the surface of the fibreboard is uneven, it is best to use an open-face style of type or design, because small openings in the dies tend to fill up and it is difficult to keep the printing sharp and clean. Lightface block letters without serifs produce the most satisfactory results.

Avoid designs with colors that butt or overlap, as trapping and register are more difficult than with metal type; colors on corrugated sometimes lap or miss by as much as 3/32 in. (2.4 mm). Large areas of solid color, especially red and orange tones, often smear and look unsightly. Keep the printing at least 0.5 in. (12.7 mm) away from horizontal score lines, as the depression made by the scoring wheels of the combiner will not take the ink properly. It is best to also avoid vertical scores, but this is not as critical. If there is printing in this area, the ink may be picked up on the scoring wheels of the printer-slotter and transferred along the score line.

In laying out copy to be printed on the box, the alphanumeric and bar-code identification of contents should be repeated on at least one end and one side panel in bold type not less than 1 in. (2.54 cm) in height (and four-side identification is even better). This information also can be carried on one of the top flaps along with the handling and storage cautions, but the other top flap should be left blank for the consignee's name and address and other shipping data (see Figure 14.8).

The quantity and size of contents can be placed in the upper left corner of each panel, with the stock number in the upper right corner. In the center should be the brand name, variety, and product name. Manufacturer's name and address can best be put on the bottom of two to four panels. The information that should be put on the bottom flaps with the box maker's certificate includes the stock number for the box and date of box manufacture. Also useful is the length of long tapes used for box sealing (if tape sealing is used) and the pallet pattern diagram.

Stacking Strength

Throughout the existence of corrugated boxes, researchers have studied the design factors contributing to stacking strength and the environmental conditions that detract from this strength. The many studies and the step-by-step advances in development of the mathematics by which box strength is predicted are beyond the scope of this book. However, a quick guesstimate of stacking strength and a look at the development of one important formula is useful to all box designers.

A rule of thumb for long-term storage is to use one-fourth of the compressive strength of a corrugated box as a safe load. For example, if an empty box with flaps sealed was found to collapse under a force of 800 lb (363 kg) in a compression tester, a stacking load of 200 lb (90.7 kg) on the bottom box in the stack would be the maximum for normal warehouse conditions.

A more accurate method for a rough-and-ready calculation of compression strength is to also take into account the fatigue factor for the length of time the material is expected to remain in storage and then apply a factor for moisture, depending on the climate and season. To determine stacking strength by this method, refer first to Figure 14.9. Find the value corresponding to the perimeter of the box (the inside length + width 2), the Mullen test value, and the type of flute. The figure on the chart is the load that can be instantaneously supported by the box for a few days. Multiply by the percentage figure selected from Table 14.5, corresponding to the expected storage period. Then choose the highest humidity condition in Table 14.6 that is likely to occur during this storage period and multiply by this factor. This will give the maximum safe load that can be supported by the bottom box in a stack, assuming, of course, that the box is properly made. These

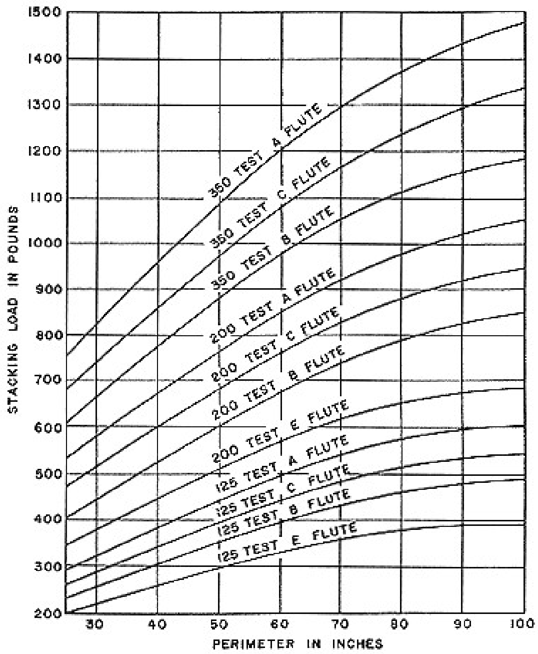

Figure 14.9.
Although this is an oversimplification of a complex set of calculations, this graph showing normal stacking strength of RSCs is accurate enough for most purposes. For tall, narrow boxes or large amounts of printing, deduct 10 percent. Double-wall board will be 50 percent stronger than the figures indicated for single-wall board of the same test. Other factors given in Tables 14.3, 14.4, and 14.5 also can be applied to the values shown on the chart.

TABLE 14.5. Fatigue Factors.

Duration of Load	Stacking Strength, Percent
Short term	100
10 days	65
30 days	60
100 days	55
1 year	50

two methods assume that the contents are not self-supporting and that the box must support the entire load.

However, the traditional Mullen burst strength of a box cited in the formula above really has little to do with its stacking strength. So researchers have spent many years developing a satisfactory Edgewise Compression Test (ECT). Only recently has it been accepted as an alternative measurement of corrugated strength and one that is more appropriate to modern warehousing and transport practices.

One of the first discoveries is that load distribution is not equal on all top edges and panels of a box. The greatest intensity is near the vertical corners of a box. The center areas of the box perimeter carry only one-half to two-thirds of the load supported by the perimeter corners.

The design of a test that would equate these and other differences in corrugated board parameters also was hampered by the fact that A-, B-, and C-flute boards differ in compression strength. Finally, an ECT sample was created that allows one formula to fit all flute sizes with creation of corrugated test specimens that are consistently 2 in. (51 mm) wide, but differ in height: A-flute being 2 in. (51 mm); B-flute, 1.25 in. (31.8 mm); and C-flute, 1.5 in. (38 mm). One-quarter in. (6.35 mm) at the top and bottom of the sample is dipped in wax to stiffen the unsupported cut ends of the vertically oriented flutes.

TABLE 14.6. Humidity Factors.

Humidity, Percent RH	Stacking Strength, Percent
Dry	100
25	90
50	80
75	65
85	50
90	40

The formula, created over many years of compression study by a team of specialists at the Institute of Paper Chemistry, is known by the name of the group leader, R. C. McKee. The original McKee formula for predicting compression strength of corrugated boards is quite complex and is used where great accuracy is required. But further studies have now enabled it to be simplified to a calculation that is sufficient for general use by packagers:

$$C = 5.87\, P_m \sqrt{h \times Z}$$

where

C	=	top-to-bottom compression strength, lb
P_m	=	edge crush test (ECT) crush, lb/in.^{2}
h	=	box height, in.
Z	=	box perimeter ($2L + 2W$), in.

Great attention should be paid by packaging technologists to the determination of how strong a box must be in compressive strength. A packager may not stack pallet loads more than two high. But owners of transit, distribution, and customer warehouses, today, want to use every vertical inch to avoid having to build new warehouses. Many present warehouses can stack pallets at least four high. Furthermore, the southern states maintain high temperatures and humidity for a good part of the year. These are three of the four deadly enemies of transport packaging (the fourth is distribution vehicles).

While corporate managements habitually single out transport packaging for its "outrageous" expense and constantly seek to reduce its cost, the actual facts are quite different. There is a substantial amount of damage in transport and storage due to inadequate or under packaging. Reduction of these damage costs is the proper route to realizing the value for all products produced and shipped.

Closing and Sealing

The most economical way to seal boxes, if labor is not an important factor, is with adhesive. Both railroad and motor freight regulations now simply require that corrugated boxes be securely closed and that the method be of adequate strength and quantity to maintain the assembly and closure during transportation. Gluing makes a very strong package when properly done, but has the disadvantage of making the box difficult to open, and sometimes dirt will sift in where the flaps meet.

Three strips of tape at top and bottom of the box will make a dust-free seal, which is strong and easy for the user to open (see Figure 14.10). Tape must be made from 60-lb (97-g) basis weight kraft paper at least 2 in.

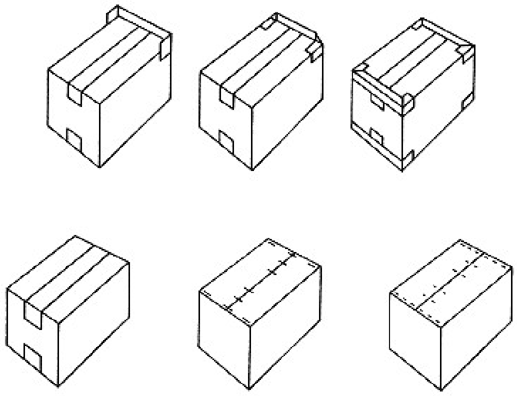

Figure 14.10.
Closure methods for corrugated boxes include a dustproof seal produced by three strips of gummed tape applied top and bottom, as shown in the first row; a single strip of reinforced tape at top and bottom (second row, left); wide-crown staples (second row, center); and regular metal stitches (second row, right).

(5.1 cm) wide and cover the entire length of the joint. It is recommended that the tape extend onto the end panels about 1.5 in. (3.8 cm). The end seams also must be covered, if plain tape is used, and it is preferable to turn the corner and run onto the flap score about 2.5 in. (6.4 cm) on each side. A single strip of reinforced tape at top and bottom may be substituted for the three strips of kraft tape, provided it is 3 in. (7.6 cm) wide and meets the strength requirements of Rule 41. Pressure-sensitive tape is permitted under Sec. 7 of Rule 41. One option is a 2-in.-wide (5.1 cm), 0.002-in.-thick (0.05-mm) polyester. Polypropylene and polyvinyl chloride tapes are available, too, at lower costs.

Advantages of tape are low-cost application equipment, no clean-up mess, and transparency. The disadvantage is its higher cost. Tape is not recommended for underfilled cases—there is not enough back pressure for adequate sealing—or for overfilled cases, which can pop open.

Stitches made from coiled wire or preformed staples may be used to close the box securely. This clean, dry operation produces a strong package, which is easily opened at its destination, but there is some risk of damaging the contents unless a corrugated pad is provided at top and bottom. Stitches must not be more than 2.5 in. (6.4 cm) apart on each side of the center seam where it overlies the inner flaps, and across both ends 1 to 1.5 in. (2.5 to 3.8

cm) from the edge of the flap. Staples usually are 1.25 in. (3.2 cm) wide and placed not more than 5 in. (12.7 cm) apart across the center seam where it overlies the inner flaps.

Testing

A new design for a corrugated box should be thoroughly tested before it is put into full production. Various tests can be used, some of which are described in Chapter 18, Test Methods. The choice of tests will be determined by the type of product to be packed. If it is fragile, a drop test will be very important. For rail shipment in carload lots, a drop of 12 to 18 in. (30.5 to 45.7 cm) on a couple of edges and the bottom should be adequate. Parcel post shipment calls for a much more severe test, in the range of 30 to 48 in. (76.2 to 121.9 cm) on several corners, edges, and flat surfaces.

If scuffing is likely to be a problem, vibrating for about 45 min. should give an indication of what may happen in a typical domestic shipment. A revolving drum test for about 30 falls or an incline-impact test from the fourth zone (9 mph, 14.5 kph) also can be used. Unless the content is selfsupporting, it is recommended that a stacking-load test be run for several weeks, if time permits.

General References

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Maltenfort, G. G. 1996. *Corrugated Shipping Containers: An Engineering Approach.* Plainview, NY: Jelmar Publishing Co., Inc.

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Chapter 15— Wood Containers

Introduction

One of the earliest packaging materials, and one that is still very useful, is wood in its various forms. Although used less frequently as more sophisticated materials are substituted, it still has an important place in industrial packaging for shipping large, heavy, and/or fragile items of any size that require rigidity and strength in the package structure.

For example, most large household appliances, bulky or dense industrial parts, and many military items continue to be transported and stored in wooden containers. In the form of pallets, wood supports almost every kind of product through the distribution chain and even is used as a display medium in warehouse stores that showcase products in shippers and on pallet loads. Skids are used as broadly, generally as in-factory carriers.

The different types of packaging made from lumber, veneer, or plywood include tight nailed wood boxes and crates, wirebound boxes, tight and slack barrels, baskets and hampers, pallets and skids, and other containerization units. Veneer is defined as wood that is less than 3-in. (7.6-cm) thick, regardless of whether it is sawed, sliced, or rotary-cut. The types of fasteners that are used include wire, nails, screws, staples, and bands.

History and Statistics

Lumber has been used for various packaging purposes since before the Christian era. The earliest sawmill in this country was set up in Jamestown, Virginia, in 1625, followed by one in Berwick, Maine, in 1631. By the early part of the nineteenth century the center of the lumber industry had shifted to the Midwest, followed by the development of the softwood industry in the southeastern states, and the opening of timberland in the Northwest.

In 1905, the U.S. Forest Service, Washington, D.C., started a program of tests for the improvement of wooden shipping containers at Purdue University, Lafayette, Indiana. The Forest Products Laboratory was established at Madison, Wisconsin, in 1910. Since that time various branches of the government, notably the military departments, have accumulated a large amount of data on the design of wood boxes and crates.

Most of the lumber used throughout the world is produced in the United States, the former Soviet Union, Scandinavia, and Canada, although in recent years, exploitation of the vast tropical forests in South America, India, and Southeast Asia has begun.

Characteristics of Wood

Wood is a structural material developed by nature to support the foliage and fruit of trees and is remarkably strong for its weight. Being a natural material, it is not very uniform in its physical characteristics, however, and it becomes necessary to select and treat it to make it useful as a packaging material. Some types of wood and certain parts of the tree are better suited for packaging than others. Even growing conditions will have an effect on the wood's strength and other qualities.

Fortunately, by selecting the proper variety, sorting it for knots and other defects, drying it carefully, and sometimes laminating it to make plywood, it is possible to produce a fairly uniform material suitable for packaging. About fifteen times stronger with the grain than across it, wood has a tendency to split when fastened together to make a box or crate, and to shrink and warp on standing. Nevertheless, it is a valuable component for large packages.

Advantages and Disadvantages

With a good strength-to-weight ratio, wood is an economical structural material. It does not require very sophisticated equipment to construct a box or crate, and for very rigid structures in small quantities, it is the material of choice.

Wood is prone to attack by moisture, insects, and fire. However, in recent years Food and Drug Administration-approved nontoxic sealants have been developed to treat lumber and create a product called “enhanced wood.” Containers made from treated wood can be washed and steam cleaned repeatedly, are flame retardant, and resist molds, mildews, and insects.

For small packages or for large quantities of packages, however, wood does not lend itself to high-speed operations or automatic assembly; it therefore has a high labor factor in relation to material cost. It also is bulky and often presents a problem of storage space and shipping cubage.

If rigidity, stacking strength, protection from the hazards of shipping, and light weight are essential, it is difficult to find a better material than wood. But if protection from moisture or atmosphere, rapid assembly, ready availability, or attractive appearance are more important, then wooden containers may not be the best answer.

Selection Criteria

There are about 1,000 species of trees in the United States. About 100 are commercially useful, but only about 10 are really important. Wood varies in density from 0.32 to 1.15 lb/in^3 (8.86 to 31.8 g/cm^3). The heavier woods are stronger and have greater nail-holding power, but are harder to work and have a greater tendency to split and shrink. As a result of work done by the Forest Products Laboratory, wood for box construction is divided into four groups, according to strength and nail-holding power (see Table 15.1).

(1) Group I includes the softwoods and light hardwoods, such as fir, pine, spruce, cedar, chestnut, willow, bass, and poplar.

(2) Group II woods—Douglas fir, hemlock, yellow pine, and tamarack—have better nail-holding power, but greater tendency to split than Group I and, therefore, require smaller nails spaced closer together.

TABLE 15.1. Grouping of Commercial Box Woods.

Group I		Group II	Group III	Group IV
Alpine fir	Magnolia	Douglas fir	Black ash	Beech
Aspen	Noble fir	Hemlock	Black gum	Birch
Balsam fir	Norway pine	Larch	Maple (soft or silver)	Hackberry
Basswood	Redwood	North Carolina pine	Pumpkin ash	Hickory
Buckeye	Spruce	Southern yellow pine	Red gum	Maple (hard)
Butternut	Sugar pine	Tamarack	Sap gum	Oak
Cedar	Western yellow pine		Sycamore	Rock elm
Chestnut	White fir		Tupelo	White ash
Cottonwood	White pine		White elm	
Cucumber	Willow			
Cypress	Yellow poplar			
Jack pine				
Lodgepole pine				

*TABLE 15.2. Typical Box Lumber Sizes for Group II Wood and Type 2 Load.**

Weight, lb	Sides, Top, and Bottom, in.	Ends, in.	Cleats, in.
50	¼	½	½ × 1½
85	5/16	½	½ × 1½
125	⅜	⅝	⅝ × 1½
225	⅜	⅝	⅝ × 1¾
325	½	¾	¾ × 1¾
425	⅝	¾	¾ × 2⅝
600	¾	¾	¾ × 2⅝

*Weights are maximum and dimensions are minimum recommended.

(3) Group III contains the intermediate hardwoods such as black ash, gum, sycamore, and elm. About equal to the Group II woods in strength and nail-holding power, but less inclined to split, these woods are the best for box ends and cleats and furnish most of the lumber for wirebound and plywood boxes.

(4) Group IV, the hardest woods, such as oak, maple, hickory, and white ash, are difficult to work, but make the strongest wirebound and plywood boxes.

Lumber should have about 15 percent moisture for best results. It should not have knots larger than one-third the width of the board and none in the nailing area. Other defects that should not be excessive are checks, splits, cross grain, decay, and insect damage.

The thickness of lumber to be used will depend upon the group of wood from which it is made, the type (easy, average, or difficult) and weight of the load (see Table 15.2).

The load is classified Type 1 if it is not very heavy, not easily damaged, and completely fills and supports the box. Type 2 average loads support the box at several points and may be held in place with interior packing. Type 3 loads tend to shift and require a high degree of protection.

Nailed Boxes

The wooden box is a very strong and satisfactory container for moving goods through difficult environments. They can be made from either soft- or hardwoods, which should be seasoned to prevent warping.

Advantages and Disadvantages

Wood for nailed boxes is abundantly available in the United States in many types and forms. Nailed boxes are very easily fabricated in any carpenter shop or manufacturing plant, and relatively inexpensive to produce in small numbers. The containers also offer great compressive strength and resistance to impacts and puncturing forces.

However, in the United States where disposal has become a costly and environmentally delicate function, wooden containers of all kinds can be troublesome unless reusable in a closed-loop distribution system. Municipalities find bulky containers expensive to collect and discard. Boxes also are heavy, difficult to open, and permeable to both moisture and gases, requiring a sealed liner to protect delicate products.

Selection Criteria

There are various methods of constructing a nailed wood box, depending upon the type of service required (see Figures 15.1 and 15.2). A Style 1 box is the simplest, consisting of sides, top, bottom, and ends without cleats. Style 4 is similar, but has two vertical cleats on each end. Style 5 is the same, except that the cleats are put on the inside. Styles 2, 2-1/2, and 3 have four cleats on each end, placed along the four edges. The only difference among them is the way the ends of the cleats are notched or mitered together. Style 6 is made without cleats, but with the vertical edges tenoned and glued.

The Style 1 box is adequate for loads up to about 60 lb (27 kg), Styles 4 and 5 will accommodate up to about 200 lb (91 kg) and Styles 2, 2-1/2, and 3 are designed for up to 600 lb (272 kg) or more.

The size and spacing of nails is one of the most important factors in the ultimate strength of a box. The size of the nails will depend on the species of wood and its thickness. Spacing will be determined by nail size and whether they are driven into the side grain or the end grain (see Tables 15.3 and 15.4).

Coated nails have 40 percent more holding power than plain nails, and side-grain nailing is nearly twice as strong as end-grain. Where it is possible to clinch the nails, as in attaching cleats, the withdrawal resistance is increased 50 to 150 percent. Cleats should not go quite to the edge of the box, as shrinkage may leave them protruding and they may be knocked off.

A modified beam formula was developed by C.A. Plaskett of the Forest Products Laboratory to determine the minimum thickness of the lumber for the top, bottom, and sides of a nailed wood box:

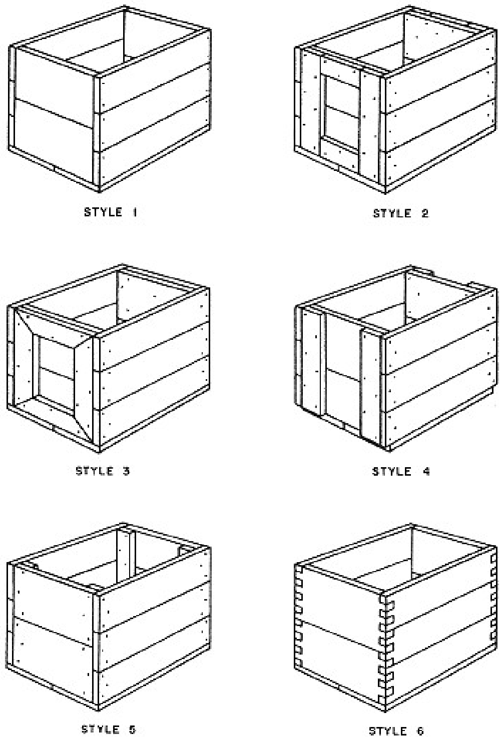

Figure 15.1.
Wooden boxes can be constructed in various styles: Style 1 is used for Type 1 and 2 loads weighing up to 60 lb (27.2 kg). Style 2 can be used for loads up to 600 lb (272.2 kg). Style 2-1/2 (not shown) is similar except that the vertical cleats are notched to receive slightly longer horizontal cleats. Style 2-1/2 and 3 also can be used for contents weighing up to 600 lb (272.2 kg). Style 4 has only two cleats on each end and a weight limit of 200 lb (90.7 kg). Style 4-1/2 (not shown) has horizontal instead of vertical cleats and a weight limit of 200 lb (90.7 kg). Style 5 has interior vertical cleats, either rectangular or triangular, and can hold up to 200 lb (90.7 kg). Style 6 has a weight limit of 100 lb (45.4 kg). End pieces and cleats are usually one-and-a-half to two times the thickness of the sides, top, and bottom, except that Style 6 is always the same size throughout. There is also a Style 7 (not shown). It's similar to Style 5, but inverted. The contents is attached to the loose bottom piece, and the sides and top form a hood. Skids are fastened to the bottom. This box style is used for loads up to 1,000 lb (453.6 kg).

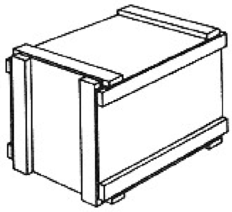

Figure 15.2.
A cleated panel box consists of solid panels of fibreboard or plywood reinforced with wood cleats. Other configurations vary in the number and placement of the cleats. Loads can weigh 150 lb (68 kg) or more, depending on the construction.

$$\text{Thickness, in.} = 1/8\sqrt{\frac{\text{Gross weight of box and contents, lb}}{\text{Width of top or sides across grain, in.}}}$$

Assembly and Closure

Before the style and size of box is even selected, the protective requirements of the product should be determined. Does the product require environmental protection in the form of cushion wrappings or sealed inner bags to guard against vibration, dropping, and/or atmospheric deterioration? This will influence the size of the box and may affect the positioning of inside cleats.

Assembly is relatively easy with nails or screws. Products that are subject to impact or vibration damage should have a space allowance around all sides of the product sufficient to hold the requisite amount of dunnage (see Chapter 16, Cushioning and Chapter 18, Preshipment Testing to determine the type and amount of cushioning required).

Box lids are nailed or screwed into place. Steel bands also may be used to discour-

TABLE 15.3. Sizes of Nails for Wood Boxes.

	Thickness of wood holding points of nails, in										
Type of wood	3/8	7/16	½	9/16	5/8	¾	7/8	1	1¼	1½	1¾
Group I	4d	5d	5d	6d	7d	8d	9d	10d	12d	16d	20d
Group II	4d	4d	5d	5d	6d	7d	8d	9d	10d	12d	16d
Group III	3d	4d	4d	5d	5d	6d	7d	8d	9d	12d	12d
Group IV	3d	3d	4d	4d	4d	5d	6d	7d	9d	10d	12d

Table 15.4. Spacing of Nails for Wood Boxes.

	Distance between Nails	
Size of Nails	Side Grain, in.	End Grain, in.
3d to 6d	2	1¾
7d	2¼	2
8d	2½	2¼
9d	2¾	2½
10d	3	2¾
12d	3½	3
16d	4	3½

age pilferage and permit a one-third reduction in the thickness of lumber used for the top, bottom, and sides. Two bands should be placed one-sixth the length of the box in from the ends, with bands in between for very long boxes (see Figure 15.3).

Wirebound Boxes and Crates

The first wirebound container is said to have been produced in Chicago in 1891 from a continuous sheet of wood veneer with wires stapled to it, improved in 1904 by stapling the wires to precut faceboards and automated in production by 1906.

Very thin lumber is used to make wirebound boxes (a rigid container with closed faces) and crates (a rigid container of framed construction, which may have open faces or be sheathed). Additional strength is provided by wires stapled around the girth of the container at frequent intervals. Wood cleats

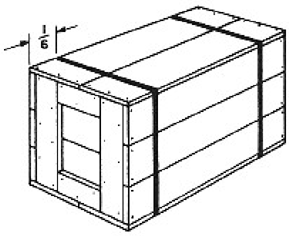

Figure 15.3.
The stress on the nails is relieved and bulging is minimized by positioning straps correctly in from each end by one-sixth the length of the box.

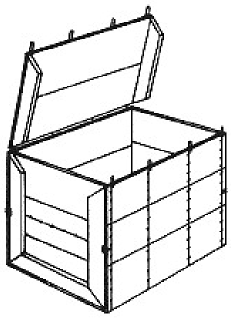

Figure 15.4.
Wirebound boxes and crates are assembled from thin face boards reinforced by binding wires that are stapled in place at frequent intervals and by wood cleats on the ends. The cover is closed by putting the wire loops through mating loops and bending them over. Capacities up to 5,000 lb (2,268 kg) are possible

are placed at the ends and sometimes in between. These cleats are mitered and also may be tenoned to lock together when assembled (see Figure 15.4). On occasion, corrugated is substituted for some of the wood or used as an interior liner to cushion product, and plastic tape replaces the wires.

Stock styles abound, many targeted to specific fruits and vegetables. Capacities range from 0.75 to 40 bu (0.93 to 49.8 ft^3 or 0.03 to 1.4 m^3) and weights up to 5,000 lb (2,268 kg) can be handled in some designs. The most economical shape for a given amount of cubic contents is with the length two to two-and-a-half times the width.

Wirebound containers are shipped and stored in the flat to conserve space and in this knocked-down form are called "shooks." The ends usually are shipped separately. Hardwoods from Groups III and IV generally are used and knots are avoided as much as possible as is divergence of grain, which should not be more than 1 in. in 8 in. of length (2.5 cm in 20 cm). The wood should be dry, with moisture not over 15 percent and, preferably, around 10 percent.

Advantages and Disadvantages

Wirebounds offer low tare weight, high stacking strength even when wet, and easy manual or automatic assembly and handling. In crate designs, openings speed chilling and allow produce to breathe or provide product visibility, which tends to promote more careful handling.

Lighter than nailed boxes because only half the lumber is required, wirebounds offer great tensile strength as a result of the reinforcing wires. Nevertheless, wirebound boxes and crates do not resist punctures or stack as well and are not as readily available as nailed wood boxes, which can be made in any carpenter shop. Since a wirebound container requires very special equipment for attaching wires and cleats, production is more restricted and shipping is a bigger proportion of its cost.

A large quantity of wirebound boxes/crates must be purchased at one time to make it worthwhile to set up the equipment. However, if quantities are sufficient, wirebounds are more economical to purchase because the containers can be assembled more quickly and with less skill than other types of rigid shipping containers. Shipping in knocked-down form, creates denser loads and conserves storage space.

Selection Criteria

The most popular All-Bound style (called the Bruce Box abroad) spaces the faceboards to provide ventilation and is widely used to transport fruits and vegetables. For heavier industrial and military items, the facings are laid closer together and made of thicker wood. This box also is characterized by wires on all six sides.

A variation, the wirebound pallet box, may have cleats inside or outside of the facings with the bottom ones fastened to the pallet. These very strong containers are used to hold ware-in-process in factories or as shippers for a wide variety of very heavy industrial goods.

Almost any Group III or Group IV deciduous wood is satisfactory for the faceboards and even some Group I and II high-density coniferous woods can be applied in special cases. The wood is cut either on specially equipped veneer lathes or by band saws from rough-cut lumber. The thin lumber ranging from 0.11 to 0.375 in. (2.8 to 9.5 mm) thick will spring under impact and absorb shocks that otherwise would be transmitted to the contents.

There are four styles of wire closures to hold the cover in place for shipment:

• Style 1 has straight wires that are twisted together. It cannot be opened and reclosed as readily as the other styles.

• Style 2 has the wire turned back to form loops that are hooked into each other and bent back.

• Style 2A also has loops, but in addition to being turned back, the end of the wire is twisted on itself for greater security.

• Style 3 has a looped wire closure, the same as Style 2, but in addition has wires across the ends in place of battens; it is not recommended for severe conditions of shifting loads, frequent handling, or overseas shipments.

The low-carbon steel wire used for wirebounds ranges in strength from 45,000 to 125,000 psi (310,275 to 861,875 kPa). The physical properties of this wire are very important since it must have stiffness, as well as ductility and great tensile strength. The staples are made from bright or galvanized wire.

Assembly and Closure

The blank or shook is delivered flat to the point of assembly. The sides should be lifted up from the bottom slightly before folding up. The sides are then folded at right angles to the bottom. The ends are nailed to the side cleats with 2.5-in. (6.4 cm) drive screw nails that go three-quarters of the way through the cleats and are spaced about 2 in. (5.1 cm) apart. The side cleats should be nailed at 4-in. (10.2-cm) intervals to the adjacent battens.

After the box is filled, the cover is brought down and the wires are passed through the loops and tightened with simple tools. Automated equipment is available where a large number of wirebound boxes are to be set up and can feed, position, and square up to 1,350 containers per hour [1]. One seven-penny nail is driven through the cleat into the end of each batten, top and bottom, to complete assembly and closure.

Since wirebound containers often are custom-made, the manufacturer must be given careful specifications if a satisfactory container is to be produced. Necessary data include the product to be carried, its weight and protective needs, and the types of handling, transport, and stacking height that will be encountered in the distribution environment.

Crates

The essential difference between a box and a crate is that, in the latter, the emphasis is on cleats and battens to take the stresses and support the contents. In a crate, sheathing is of minor importance and may be entirely omitted in some instances.

A crate most often is used for items that are too large for a plain wooden box. It may be nailed or screwed together, and will often incorporate runners on the bottom to allow a fork truck to get under and pick it up. Steel bands can be used to reinforce the corners or may be put around the girth. Metal straphangers, timber connectors, and other hardware from the building trades will be found useful for very large jobs.

Design

The diagonals, struts, and long members of a crate should be selected in much the same way that an engineer designs a Howe truss for a bridge. The crate designer has the advantage of being able to use sheathing to strengthen his structure. The choice of lumber and fastenings as described for nailed boxes applies to crates as well (see Table 15.5).

The importance of having diagonal members in every panel cannot be overemphasized. A framework with diagonal members will be ten times stronger by actual test as a framework with the same pieces of lumber placed parallel or perpendicular to one another. A long, narrow crate should be divided into approximately square sections by perpendicular struts, and each of these sections should have a diagonal from corner to corner. The diagonals in adjacent panels should go in opposite directions, so that there are as many one way as the other throughout the crate. Diagonals must resist about the same stresses in tension and compression as the vertical and horizontal pieces, and therefore should be made of the same size lumber (see Figures 15.5 and 15.6).

The contents should be completely enclosed with no parts protruding and must be fastened so there's no movement within the crate. Polished product surfaces should be at least 1 in. (2.5 cm) away from any part of the crate and all surfaces sensitive to environmental or physical forces must be carefully covered. Detachable parts should be removed and packed in a cloth or

TABLE 15.5. Size of Lumber for Crates.

			Size of Main Structural Members, in.		
Load, lb	Spacing of Cleats and Battens, in	Size of Cleats and Battens, in.	2-ft Spacing	4-ft Spacing	6-ft Spacing
100	54	¾ 2¼	¾ 2¼	¾ 2¼	¾ 2¼
200	48	1 2	1 3	1 4	1 5
500	42	1 3	1 4	1 5	1 6
1,000	36	1 4	1 5	1 6	2 4
2,000	36	1 4	1 6	1 6	2 4
5,000	24	1 4	1 6	2 4	2 4
10,000	24	1 6	2 4	2 4	2 4

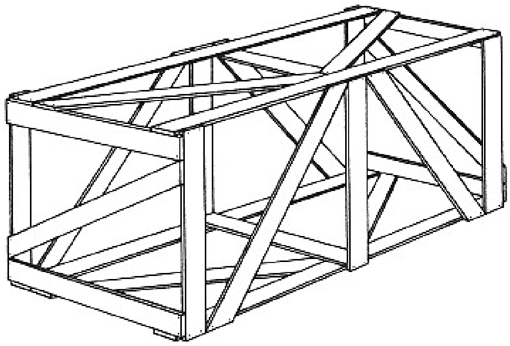

Figure 15.5.
This simple crate is suitable for light duty. Very heavy loads would require a much stronger construction with screws or bolts instead of nails.

heavy plastic bag, corrugated or wood box, which should be secured inside the crate. Movable parts must be braced or blocked, and one should not depend on latches or locks to hold doors and drawers in place. Twine, wire, or a good grade of pressure-sensitive tape should be used to secure grilles and covers.

Items with legs should be suspended so that the legs are at least 1 in. (2.5 cm.) away from any part of the crate. Place supports under the strongest part of the article, and put blocks or bracing on the sides and top, as near the center of gravity as possible.

Other considerations in design are the forces to which the crate will be subjected, the need to design the smallest and lightest structure compatible

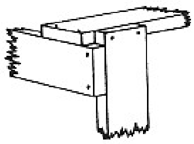

Figure 15.6.
The three-way corner where every nail goes into side grain, and each member is locked in by the other two members is the strongest construction for a crate because nails are not likely to work loose.

with these forces, and a minimum volume, since shipping charges often are based on volume as well as weight. Product considerations include the need for environmental coverings or containment, handling and stacking situations that could be damaging to the product, and requirements for storage over a specific time frame.

Baskets

Fresh fruits and vegetables often are packed in baskets made from thin wood veneer. The baskets come in several different styles, and in sizes that were established by the Standard Container Acts of 1916 and 1928. Berry baskets, known in the trade as "small goods," are made in pint and quart sizes as well as "tills" (larger oblongs). The climax style is oval with a board bottom, and comes in 24-, and 12-qt (22.7- and 11.4-L) sizes. Round "continuous stave baskets" with a rounded board bottom usually have a handle on each side and can be supplied with stave covers. Hampers come in the same sizes as the round-bottom baskets, but are taller and narrower (see Figures 15.7 and 15.8).

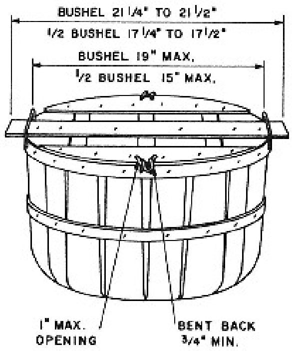

Figure 15.7.
Continuous-stave basket with round bottom is used for citrus fruits and other fresh produce. Some baskets have a flat bottom with continuous staves, or a solid or built-up bottom. Cover is held in place with wire bails and loops or with cross wires or sheet metal fasteners. Dimensions shown are recommended for safe handling.

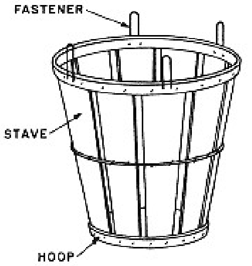

Figure 15.8.
Made from veneer, which has been rotary-cut against a stationary knife, these fully set-up hampers can be nested to save space. Various sizes from 1/8 to 1.5 bu (0.004 to 0.05 m^3) are made to dimensions prescribed in the U.S. Standard Container Acts of 1916 and 1928.

Barrels

Originated more than 2,000 years ago, barrels embody several sound engineering principles (see Figure 15.9). The staves are arched in two planes, forming the ideal eggshell for maximum strength. The "bilge" (bulge) makes the barrel easy to roll and convenient to upend. The flat ends provide a stable bottom for storage, and the hoops may be worked down toward the bilge to draw the staves together and make the barrel leakproof, at the same time locking the head into the "croze" (groove in the staves). A barrel is like a container on wheels. It can be rolled easily by one person, and because of its bilge, pivots readily and can be guided in any direction. Upending is accomplished by rocking back and forth on the bilge, and the chime provides a convenient handle for giving the final tug to stand the barrel on end.

A barrel differs from a drum in being bulged. Other terms are "cask," which is a large tight barrel; "keg," a small tight barrel of 10 gal (37.9 L) or less; "tierce," a barrel of 42-gal (159-L) capacity; "firkin"; and a tub that holds 56 lb (25.4 kg) of butter. (Strictly speaking, a "tub" is smaller than a firkin and holds only about 4 gal (15 L). A "pail" is larger at the top than the bottom and, by definition, has a handle or bail for carrying. A "kit" is an upside-down pail that is smaller at the top than the bottom.

Barrels generally are divided into two classes, tight to hold liquids and

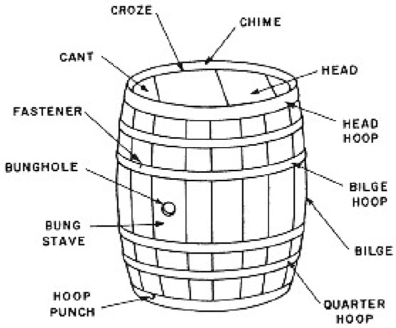

Figure 15.9.
Barrels in volumes from 1 to 60 gal (3.8 to 227 L) can be constructed from a variety of woods and designs. The number of hoops made of steel, wire, or wood will vary according to the size and type of barrel.

slack for dry products. Tight barrels are usually coated on the inside, depending on the type of product to be packed. Wax often is used as a lining material for aqueous products, silicate of soda for oily materials, and glue for alcohol-based liquids other than food products.

Selection Criteria

The staves are made of many varieties of wood, and the choice is largely a matter of the most economical type for the job, although some selection is traditional as in the use of oak for the barrels in which many alcoholic beverages are aged. One word of caution, however, in the case of food products: Certain kinds of wood, particularly in the pine family, may impart an undesirable flavor or odor to the contents.

Today, barrel staves are likely to be quarter sawn, planed inside and out, and steamed to achieve the necessary curvature. Hoops are made of steel, wire, wood, rope, or combinations of these. Some standard designs are identified by their most frequent use, such as the "meat and poultry barrel" used for meat cuts and dressed birds, usually without a cover. The "glass and pottery barrel" is similar, but with a closed head. Others are known as nail kegs, apple barrels, and a host of sometimes picturesque names derived from the products contained.

Assembly and Closure

A barrel should not be moved by rolling it on its edge or chime; it should be rolled only on its bilge or side. A loaded barrel should not be dropped, for although it is quite strong, it is not indestructible. Slack barrels should be stored on end; tight barrels on the bilge with the bung up.

To take the head out of a barrel, see whether one chime is deeper than the other and then take the head out of the end with the thinner chime. First remove the nails from the top hoop and drive the hoop up 0.5 in. (1.3 cm) or so. Then tap the head lightly until it falls into the barrel. Do not remove the head with a hammer, but loosen the top hoop and lift the head out.

To close a barrel, drive the head hoop up about 0.5 in. (1.3 cm) all around. The head is started in the croze at one point, and is gradually worked down into place by tapping with a hammer all around from that point. If the head is in several pieces, start with the middle piece and work toward the sides. The head hoop is then driven down to draw the tops of the staves in tight, and threepenny nails are spaced 6 in. (15.2 cm) apart, through the hoop and into the head.

To remove a bung, sharply tap the bung stave close to the bung until it pops out. If it does not come out easily, use a bung chisel or bung puller. If vent holes are necessary, use a tenpenny nail rather than a drill, to avoid getting chips into the interior. When replacing a bung, have the grain running the same way as the stave or head board.

Pallets

For many ages, mankind carried its packaged goods from manufacturing to storage to transport on small, wheeled hand trucks, a manual loading and unloading procedure that was both time-consuming and expensive.

The invention in the 1930s of motor-powered and maneuverable lift trucks equipped with front-end hoists initiated a change to more efficient methods, which included the creation of pallets, skids, and slip sheets to carry bigger loads of packaged goods and to stack them one upon the other, utilizing existing overhead warehouse space instead of requiring costly ground-level expansion.

The development was sealed in World War II by the military, which bought more than 50 million wooden pallets and skids to move the materials of war. With peacetime, came the invention of even smaller and specially adapted lift trucks powered by electricity and liquified petroleum gas (LPG) for cleaner indoor use than conventional gasoline engines. These trucks are capable of operating in increasingly confined warehouse corridors and truck interiors.

Also developed were standards for the construction of pallets and pallet-mounted intermediate bulk containers (IBCs) and the creation of pallets and containers made from metal, plastic and, more recently, corrugated and paperboard, as well. However, wood still accounts for more than 90 percent of all pallets made, about 455 million in 1995. At an average price of $7 each, that's a sales volume of more than $3.1 billion. However, because of expenses associated with pallets, the actual cost per trip is nearly $12 as shown in Figure 15.10.

To oversee such a sizable industry, the National Wooden Pallet Manufacturers Association was formed in 1947 and expanded its name in 1967 to the National Wooden Pallet and Container Association (NWPCA), Arlington, Virginia.

The first standardization of pallet sizes and constructions was initiated in 1945 by the brick industry, which created a specialized pool of pallets among its members. This was followed closely in 1946 by the food industry and its transportation, handling terminals, and warehouses, which recommended pallet sizes of 40 32 and 40 48 in. (101.6 81 and 101.6 121.9 cm) for inter-industry use. This industry pallet exchange and interchange is known as the GMA pool after the Grocery Manufacturers of America, Washington, D.C., which has supported the practice. The recommendations also were

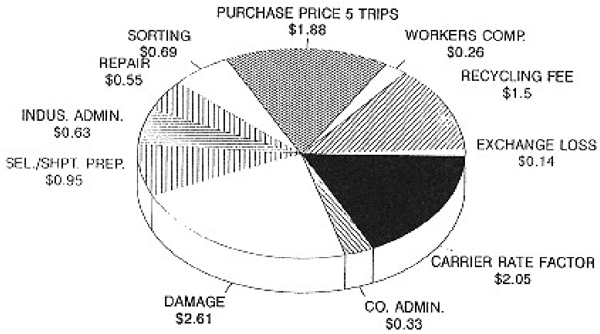

Figure 15.10.
Although pallets may only cost about $7 each, expenses associated with repair and handling bring the actual expense to $11.59 per trip.
(Source: Grocery Industry Pallet Subcommittee, Grocery Manufacturer's Association, Washington, D.C.)

adopted by the U.S. Department of Commerce, and federal pallet specifications, which included several military standards, were adopted by 1952.

In Europe, Sweden started an inter-industry pallet pool in 1947 and by 1962, thirteen other inter-industry pallet pools had arisen on the Continent. The European pool system, managed by the railroads, has been very effective. In the United States, there are a number of limited pallet pools, many confined to single large corporations with national distribution.

With this great growth in usage, the pallet industry needed research and development of both materials and structural engineering to improve the strength, performance, and maintenance of this vital packaging tool. In fact, perhaps no other packaging component has developed as much R&D.

The U.S. Forest Products Laboratory supplies engineering research in woods and pallet fastenings. The U.S. Department of Agriculture's Forest Sciences Laboratory in Princeton, West Virginia, studies the supply and demand of pallets and their materials. Virginia Polytechnic Institute (VPI), Blacksburg, Virginia, researches design and construction of pallets and fasteners. The U.S. Army's Mobility Equipment Research and Development Command at Fort Belvoir, Virginia, researches, tests, and publishes specifications for Department of Defense pallets.

The American Society of Mechanical Engineers, New York, in cooperation with the American National Standards Institute, New York, has standardized pallet definitions and terminology and ASTM (American Society for Testing and Materials), West Conshohocken, Pennsylvania, has standardized methods of construction and testing pallets [2, 3]. The NWPCA has issued standards for softwood warehouse and returnable pallets, Douglas fir and softwood plywood pallets, hardwood and white woods pallets, West Coast pallets, and pallet repair.

Despite this massive standardization, individual pallets of custom size and design still are abundant throughout industry. To assist such constructions, a computerized *Pallet Design System* was created in 1984 by NWPCA, VPI, and Forest Service laboratories. This reliability-based design procedure for the construction of wood stringer and block pallets is an IBM-PC Basic language program, available in either English or metric units, for use in checking the appropriateness of existing wood pallet designs, improving the efficiency of an existing design, or designing a pallet for a new use. The program, updated with continuing research, is available from NWPCA.

Advantages and Disadvantages

The breadth of types available in wooden pallets and their various engineering capabilities have been a major economic and functional asset to industry. Within limits, one pallet type has a wide range of application. Increased standards of construction and specification of material dimensions have improved performance as has an NWPCA logo certification and inspection program for pallet manufacturers. National leasing, although limited, has made supply and cost more flexible, and a newly activated national recycling program for discarded wooden pallets may solve the age-old problem of how to get rid of broken pallets stacked up behind plant warehouses.

However, pallet prices vary widely over geographical locations. Maintenance is erratic, poorly performed, or even nonexistent in many manufacturing plants, leading to the continued circulation of damaged pallets, which are a nuisance at best and potentially dangerous to handlers as well as the products stacked upon them. A common complaint among GMA pool users is that some companies sort out the best incoming pallets for their own internal use, using less-favorable or even damaged ones for outgoing shipments. Storage is often outdoors and cleaning between trips tends to be inconsistent. Where repair programs exist, costs are usually lumped into general warehousing expenses where their extent or appropriateness remains unknown.

Better than three-quarters of the annual output of pallets goes into replacement of damaged pallets. Since wood output is increasing at an infinitely smaller rate per year, pallet life span needs to be increased while the time and money spent on repairs is reduced. Many in the industry believe that this objective can only be reached with a national pool-pallet exchange system.

Inadequate care and attention by users have led to a two-fold development: (1) more expensive plastic pallets and skids, now specified in some medical-products operations, which can have a very long life and also keep dirt, insects, and splinters out of process and packaging areas; and (2) one-trip pallets fabricated from corrugated sheet and paperboard, which are both inexpensive and more easily discarded into local recycling programs. For more information on these structures, see Chapter 8, Plastics and Chapter 14, Corrugated Fibreboard.

Selection Criteria

Specifications for the materials used in pallet and skid construction are far too many and varied to be detailed here, but are described in NWPCA's *Uniform Standard for Wood Pallets.* This section will simply describe the various types of pallets and structural requirements to demonstrate the importance and engineering complexity of this packaging element.

The types of wood that can be used in pallets and its inherent defects—such as knots, wane (bark), decay, splits or shakes (variously sized cracks), and warp—are many and vary in acceptability. Lumber for pallets is graded by species, mechanical properties, regional availability, effectiveness of preparation, and actual commercial use in pallets. Defects are graded on size, physical soundness, and location in the pallet structure.

Lumber for pallets is surfaced to dimension on one, two, or four sides depending upon the grade of pallet for which it is intended. Flaws include skips where planers do not uniformly clean the board surface, torn grain where planers tear the surface, and cross-cutting where bearded or splintered ends are caused by dull saw blades, as well as deviation from square of board ends. The types of wood used in pallets are not limited (see Table 15.6) [4].

Wooden components have targeted dimensions in manufacture that are reasonably tight. Fasteners include driven nails, staples, bolts, screws, and lag bolts. Specifications for fasteners are closely controlled since their type, properties, and placement have a dramatic effect on pallet performance.

Assembly of Pallet Types

The types of pallet and skid structures are almost infinite. However, a few dominate, and the computerized design system is increasing standardization. There are basically three general groups: expendable, usually one-trip structures; general-purpose, multi-trip structures for warehouse use and transport of goods; and special-purpose, which are designed by the manufacturer and user to mutually acceptable specifications to meet the needs of a particular product or distribution system.

The general-purpose pallets are divided into "M" pallets that are designed for at least ten trips to "life-to-first-repair," assuming five handlings per trip in an average handling environment as defined in the Pallet Design System; and "L" pallets, designed for up to nine trips under the conditions described above.

The two common pallet designs are two-way entry, which permit lift-truck and hand-pallet-truck fork entry on only two opposing sides, and four-way entry, which allow pallet pickup from all sides (see Figure 15.11, which also identifies pallet parts). There also are two styles of pallet, a single-face structure that has only one deck on the top surface, which is also called a skid, and double-faced pallets that are decked on the top and bottom. The latter has two variations: Top and bottom decks both accept the stacking of goods; and a double decker, which accepts goods only on the top deck. Pallets also can be faced with plywood on one or both sides and are stackable on one or both sides.

The most common type of pallet deck is flush stringer where these components are flush with the top deck. However, single-and double-wing pallets are available in which the top decks extend beyond the stringers on two

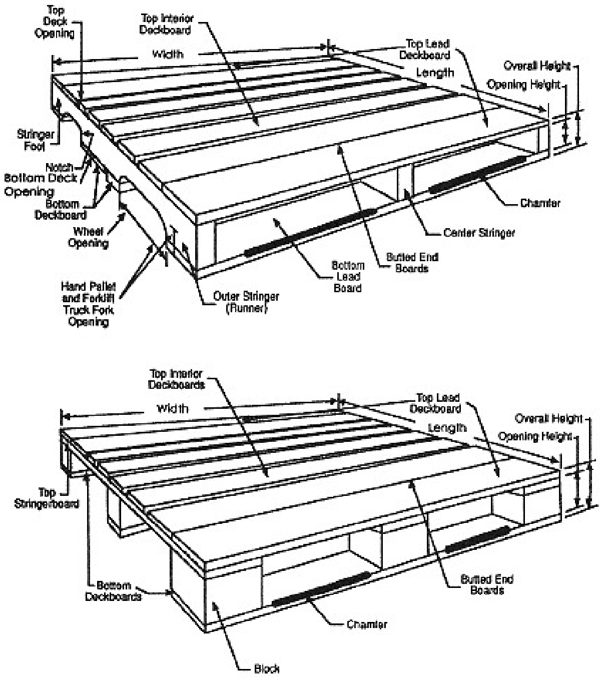

Figure 15.11.
Four-way entry pallets come in stringer (top) or block designs. (From "Figure 1," Uniform Standard for Wood Pallets, September 1, 1996, p. 2. National Wooden Pallet and Container Association, Arlington, Virginia. Reprinted with permission.)

or four sides while the ends are flush with the bottom deckboards. These pallets are very useful where it is desired that stretch or shrink wrapping assist in locking the load to the pallets. The wraps are simply extended over the edge of the wings. There is also another design where top and bottom deckboards extend beyond top and bottom stringers. This style is used to facilitate use of bar slings and like pallet-handling devices.

Driven fasteners include staples and nails, the latter plain-shank, fluted,

TABLE 15.6. Pallet Wood Classifications (North American Species).

Class 1
Hickory
Yellow Birch
Sweet Birch
Sugar Maple
Black Maple
Red Maple
Green Ash
White Ash
Rock Elm
Slippery Elm
American Beech
Black Locust
Black Cherry
Tanoak
Dogwood
Persimmon
Eucalyptus
Class 2
Bigleaf Maple
Oregon Ash
Class 3
Sweetgum
Tupelo
Paper Birch
Black Ash
Pumpkin Ash
Hackberry
Sycamore
Silver Maple
Striped Maple
Magnolia
Class 4
Oregon White Oak
California Black Oak
Cascara
Chinquapin
Myrtle
Madrone (Pacific)
Class 6
Red Alder

Source: From "Annex-A," *Uniform Standard for Wood Pallets,* September 1, 1996, p.35. National Wooden Pallet and Container Association, Arlington, Virginia. Reprinted with permission.

(table continued on next page)

TABLE 15.6. (continued).

Class 7

Bigtooth Aspen

Quaking Aspen

Catalpa

Buckeye

Butternut

American Basswood

Black Cottonwood

Balsam Poplar Cottonwood

Eastern Cottonwood

Class 11

Douglas-Fir

Western Larch

Class 12

Western Hemlock

Mountain Hemlock

California Red Fir

Grand Fir

Noble Fir

Pacific Silver Fir

White Fir

Class 13

White Spruce

Black Spruce

Red Spruce

Engelmann Spruce

Sitka Spruce

Sugar Pine

Western White Pine

Lodgepole Pine

Ponderosa Pine

Monterey Pine

Jack Pine

Norway Pine

Eastern Pine

Southern Pine

Pitch

Pond

Spruce

Virginia

Subalpine Fir

Balsam Fir

Baldcypress

Eastern Hemlock

Western Red Cedar

Redwood

(table continued on next page)

TABLE 15.6. (continued).

Class 14

Alaska Cedar

Incense Cedar

Port Orford Cedar

Atlantic White Cedar

Northern White Cedar

Eastern Red Cedar

Class 21

Eastern Red Oak

White Oak

Class 22

Southern Pine

Loblolly

Longleaf

Shortleaf

Slash

Class 29

Yellow Poplar

North American Wood Species Classes Ranked According to Relative Strength

and Stiffness

Strongest 21

1

22 (Dry)

2

11

29

4

6

3

12

22 (Green)

7

13

Weakest 14

twisted square wire, annularly threaded, or helically threaded. Pallets also can be assembled with standard, slotted, or large-head steel bolts. No matter what fastener is used, heads must be flush or recessed on deckboards and outside stringers or blocks.

The placement and number of fasteners per pallet is closely governed depending on size and style as are the number of flaws (see Table 15.7) [5]. For example, the number of fastener-caused splits that usually occur near the ends of stringers and deckboards may not exceed one per connection or

TABLE 15.7. Minimum Number of Fasteners per Pallet.

Deckboard Width	Minimum per Connection
Up to 5.25 in. (133 mm)	2
5.25–7 in. (133–178 mm)	3
7–8 in. (178–203 mm)	4
Corner block	3
Interior block	2

Corner blocks with less than 16 in.^{2} (1,032 mm^2) of blocks fastening surface shall be connected with at least two fasteners

Note: There should be no less than one nail or staple per 8 in.^{2} (512 mm^2) of block fastening surface

Bolt, Wood Screw, and Lag Bolt Fasteners: The end deckboards shall have at least two bolts, wood screws, or lag bolts, per corner connections and at least one at all other connections.

Source: From "Table 4," *Uniform Standard for Wood Pallets,* September 1, 1996, p. 13. National Wooden Pallet and Container Association, Arlington, Virginia. Reprinted with permission.

more than one-third of the total connections in a given pallet. Adhesives sometimes are used in pallet construction, but in these standards only in conjunction with mechanical fasteners. The standards also provide guidance and restrictions in pallet repair.

A discussion of wooden pallets would not be complete without mentioning another alternative, wooden slip sheets. Made of a single-layer of plywood-like material, slip sheets are considerably lighter and less expensive than pallets. Handling is by forklift with a push-pull attachment. However, a variation with a turned-up edge on one or more sides can be handled by standard forklifts with tapered forks.

Pallet Containers

Wooden pallet containers are IBCs capable of handling almost any solid, powdered, or liquid product. There are three categories: bins, boxes, and crates.

Bins have solid sidewalls made of closely fitted sawn lumber and diagonal cleats of sawn lumber for great strength (see Figure 15.12). They are normally mounted on block pallets and made in noncollapsible or collapsible designs where the box structure is folded, generally to fit within the dimensions of the pallet base for ease of shipment.

Pallet boxes generally are constructed with solid plywood sides reinforced with sawn lumber cleats and fitted plywood lids, also reinforced around the sides with sawn lumber. They carry loads intermediate in weight and, like nailed boxes, can be lined with liquid-and powder-tight plastic liners.

Often mounted on a simple skid, pallet crates are slat-sided boxes con-

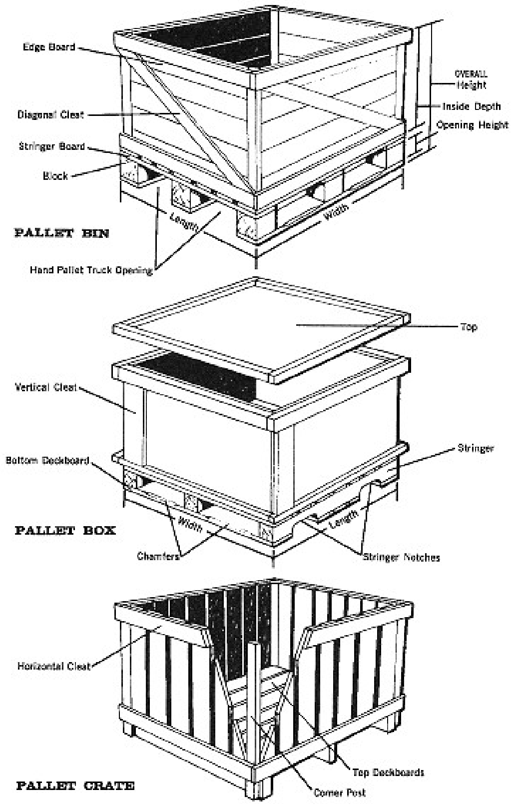

Figure 15.12.
Pallet container styles include bins, boxes, and crates. (From Wooden Pallet Containers & Container Systems, 1967, p. 3. National Wooden Pallet and Container Association, Arlington, Virginia. Reprinted with permission.)

structed with spaced sawn lumber and reinforced with internal vertical corner posts and external, horizontal cleats. These containers also can be collapsible or noncollapsible and are widely used for produce requiring a breathable container.

A number of special features are available in these transport containers. Bottom deckboards can be extended beyond the stringers to provide a wider stacking surface and latitude for misalignment in stacking. The bottom deckboards can be inset from stringer edges to permit the pallet base to fit into the top of the box underneath for greater stacking stability.

In single-wing designs used for straddle truck handling, the two top opposing sides can be extended vertically to nest with the bottom of another pallet box. The same interlocking stability can be attained by using vertically extended corner cleats on all four corners, too.

Stronger structures are made with container sides of wood constructed around a steel-rod frame or with heavy-duty, full-length steel corner hinges. Quick-assembly containers can be fitted with steel or aluminum corner braces into which sliding wooden panels are inserted. Steel strapping is used horizontally around some structures to add strength and, as has already been mentioned (see page 494), wirebound boxes can be fitted to pallets for service with intermediate loads.

References

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3. ASTM (American Society for Testing and Materials). 1994. *D-1185.94, Standard Test Methods for Pallets and Related Structures Employed in Material Handling and Shipping.*

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5. Ibid., p. 13.

Chapter 16— Cushioning

History

The most ancient of cushioning materials used in packaging for the protection of products during transport and storage are made from wood shavings (excelsior), straw (bagasse), crumpled or shredded waste paper, cellulose wadding, and rubberized hair. While still used in varying amounts, these materials have largely been replaced with cushioning created from polymers, which can be tailored for more precise protection.

Probably the most popular polymer-based cushioning is foamed. This is a plastic that has had its density substantially decreased by the creation of cellular structures dispersed through its matrix. For packaging purposes, the dispersion process generally distributes a gas throughout the molten resin which, with heat, creates void "cells" that are allowed to grow to the desired size and then fixed in place by cooling the material. The process is compatible with a number of thermoplastics and can produce rigid or flexible foams.

Rigid foams are engineering structures created by reaction-injection-molding. Packaging applications include pallets, crates, and large trays. However, rigid urethane foam is a term also used for foam-in-place cushioning to be discussed later in this chapter.

Required Data

Selecting the best type and right amount of cushioning for a particular packaging application depends, in most instances, on only three or four bits of information. There are even some rule-of-thumb figures that can be substituted for some of the variables, so that the process of designing a package for a fragile item need not be very complicated. This is not to deny that there are some complex forces involved. In most cases, however, a simplified approach to the problem will provide a completely adequate solution.

First we must know something about the fragility of the item to be packaged. Then, we must consider the hazards it will be exposed to. Finally, we must understand the characteristics of the available cushioning materials so the most economical material that will do the job can be chosen.

Typical transport hazards to which all products are subject are the vibrations and impacts imparted by the transport vehicle (see Table 16.1). If we can translate these impulses into a "G factor," we will have one of the elements needed to select the proper cushioning. The G factor is the minimum force required to create damage in an item. However, this minimum force may change if the conditions of shipment or handling change. The G factor also may be affected if a fragile component is shifted to a more or less vulnerable position in the package or even in its location in the product. (Gs are the number of accelerations of gravity at 32.19 ft/sec^2 or 9.81 m/sec^2 to which the package is subjected.)

The G factor can be determined with a shock machine or an instrumented impact test. However, fairly accurate results can be obtained by a simple trial-and-error method. Use a package similar in dimensions and material to the anticipated final design and select a cushioning material with known peak deceleration versus static stress curves (see Figures 16.1, 16.2, and 16.3). In a series of drop tests, decrease the thickness of the cushioning with each test until damage occurs. The peak acceleration on the curve before failure gives the product's approximate fragility. Some examples are shown in Table 16.2.

We also need to know the weight of the object being packaged and the area to be supported by the cushioning. Dividing the weight by the area gives the static stress in psi (kPa). If the area is not the same on all sides, the safest approach is to use the smallest area for calculations.

TABLE 16.1. Typical Transit Vibrations and Forces on Packaged Goods.

Vehicle	Frequency, Hz (cps)	Acceleration Forces, Gs
Freight car in motion	0.9–1100	0.1–2.0+
Freight car coupled at 9 mph	NA	18
Truck in motion	0.08–500	0.03–2+
Ship at sea	1.0–1100	0.05–0.3

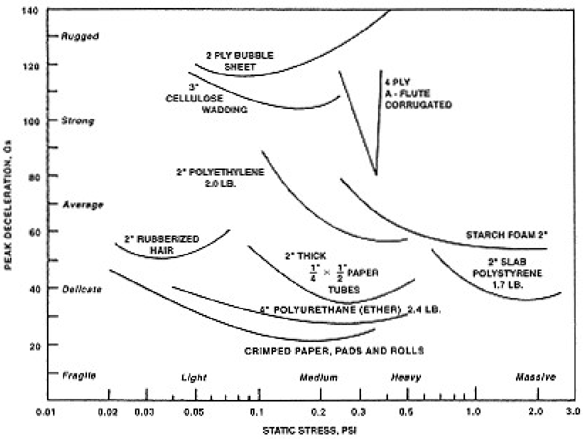

Figure 16.1.
Various cushioning materials offer different levels of protection at a 30-in. (76.2-cm) drop height at ambient temperature (70 F, 21 C). Other thicknesses, drop heights, and temperatures will move the curves up or down, but will not greatly affect positions from left to right.

The next consideration is the potential hazards the package is likely to meet in shipment. A package weighing less than 10 lb (4.5 kg) can be tossed like a basketball, but a heavier unit can be raised only waist-high and then dropped (see Table 16.3). It is also necessary to establish how many shocks the product is likely to sustain during handling and storage.

The next piece in the puzzle is the type and thickness of cushioning required to satisfy the conditions cited. The type of cushioning is dependent

TABLE 16.2. Fragility Factors for Assorted Products.

Product	Forces, Gs
Precision instruments	15
Electronic equipment	25
Television receivers	50
Refrigerators and washing machines	100
Machinery	125

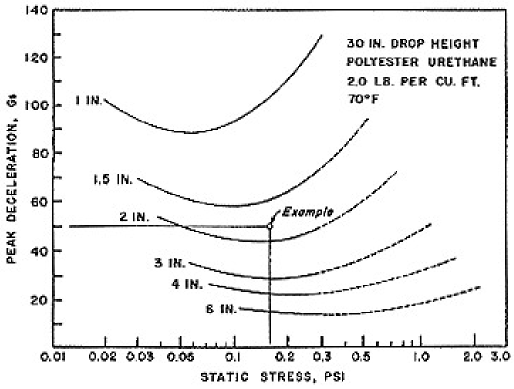

Figure 16.2.
Curves show dynamic cushioning capability of PU versus its thicknesses. If the fragility of a particular item is such that it can withstand 50 Gs and the weight per unit area of bearing surface is 0.15 psi (1.03 kPa), the intersection will be above the curve for 2 in. (5.1 cm) as shown. Any thickness below this point will provide adequate protection. Creep, which becomes a significant factor in the dotted portions of the curve, may result in as much as 75 percent loss of thickness.

upon product requirements. This information is shown in the G versus weight/unit area curves that manufacturers supply for various materials. A few reference curves are shown in Figure 16.1. Draw a horizontal line from the G factor (fragility) of the item to be packaged and a vertical line up from the psi figure derived from the weight and area and note the intersection point. Any curve that passes below this point indicates the material can be used in that thickness. A sample problem may serve to illustrate. Since most

TABLE 16.3. Typical Drop Heights in Product Handling.

Gross Weight, lb	Type of Handling	Drop Height, in.
0–20	1 man throwing	42
21–50	1 man carrying	36
51–250	2 men carrying	30
251–500	Fork-lift truck	24
501–1,000	Fork lift truck	18
1,000 and up	Fork lift truck	12

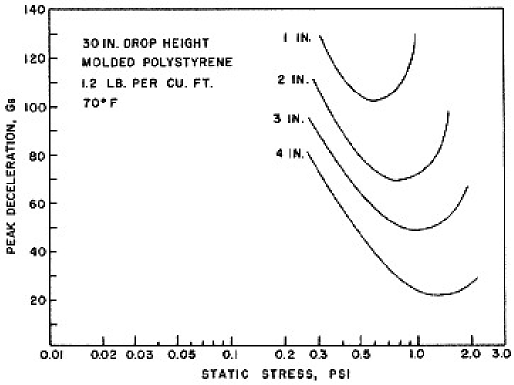

Figure 16.3.
Curves show dynamic cushioning of molded EPS in various thicknesses. Find the point where the fragility of the item intersects the dead weight. The curve that comes closest, but dips below this point, indicates the most efficient thickness of 1.2-lb/ft^3 (19.2-mg/cm^3) density material for a 30-in. (76.2-cm) drop height. If the height is reduced by half, static stress can be doubled. If the density is increased, load-bearing capacity improves only slightly, and shock absorption declines by a small amount.

charts of cushioning materials are based on a 30-in. (76.2-cm) drop, we will take this as our sample standard (see Figures 16.2 and 16.3).

Weight = 15 lb (6.8 kg)
Bearing area = 10 × 10 in. (25.4 × 25.4 cm)
Fragility = 50 G
Potential hazard = 30-in. (76-cm) drop

$$\frac{W}{A} = \frac{15}{10 \times 10} = 0.15 \text{ psi } (1.03 \text{ kPa})$$

Referring, for example, to Figure 16.2 for polyurethane foam (2 lb/ft^3 (32 mg/cm^3) density, we find where 0.15 psi (1.03 kPa) intersects the line from 50 G. We see that the curve for 2-in. (5.1-cm) thickness dips below this point, indicating that it will satisfy the requirements.

A common mistake in evaluating cushioning is the assumption that with closed-cell foams, performance is always increased by lowering foam densities. It is true that at densities below 2 lb/ft^3 (32 mg/cm^3), lower densities can begin to equate to improved cushioning performance. But low densities also decrease resistance to creep, and the idea that low densities are less costly than higher densities is not necessarily true. There are several manufacturing considerations apart from the base cost of a resin.

At higher densities, the lowering of density is more related to an increase in deceleration values or, in other words, a reduction in cushioning performance. Increased densities do not necessarily assure a cost-effective return to high cushioning performance. For example, lamination of foam layers can perform quite differently than a solid foam plank. Therefore, although paper calculations are a useful starting point, in the end, it is important that cushioning designers compare documented performance data to be certain that a selected material is effective and efficient.

Another common practice in the design of cushioning is to create ribs, generally trapezoidal in shape, on either the outer or inner surface in the belief that this feature reduces shock. Such data are not given in standard cushion curves, which are based on flat planks. But a study of expanded polystyrene (EPS) cushioning in ribbed and flat configurations has shown that at lower drop heights between 12 and 24 in. (30.5 and 61 cm), there is no significant difference in the shock levels obtained from ribbed and flat cushioning. However, at higher drop heights between 30 and 42 in. (76.2 and 106.7 cm), transmitted shock levels from ribbed cushioning were significantly higher than those from flat EPS. Also, ribbed EPS produced higher shock levels at static stresses above 1.4 psi (9.7 kPa). In multiple drop tests, the transmitted shock levels after the first drop also were greater for ribbed EPS.

A few minor considerations ought to be taken up at this point. One is the matter of creep or cold flow under a load over a long period of time. Whatever this amounts to should be added to the thickness of the cushioning material. Thus, if a 2-in. (5.1-cm) thickness of urethane foam would be satisfactory for immediate shipment, but in long-term storage would settle 33 percent, then a 3-in. (7.6-cm) thickness should be specified so the required 2-in. (5.1-cm) thickness will remain after it has settled.

Other points to consider include:

(1) Effects that abrasion of the cushioning material has on the item

(2) Settling of the cushioning material from repeated impact

(3) Comparative natural vibratory frequency of the package and that of the product. Ideally, package frequency should be below that of the product so that it damps product response. Worst case is to have both coincide, in which case, the frequencies amplify each other.

(4) Mass of the cushioning itself. This is a negligible factor, but for precise calculations, one-third of the weight of the cushioning should be added to the weight of the article in calculating total mass.

(5) Internal damping of shock vibrations. This is a plus factor that varies with different materials. It can be ignored for all but the most sophisticated investigations.

(6) Temperature and humidity, which may alter the protective qualities of certain materials. Plastics tend to stiffen at low temperatures and soften at elevated temperatures. Cellulosic materials are affected by moisture and, if this is expected to be a factor, the supplier of the cushioning should be consulted for special data applicable to these conditions.

Cushioning Materials

Foamed plastic can be defined as an expanded resinous material with a cellular sponge-like structure usually made by the introduction and dispersion of a gas in molten resin and the subsequent setting or curing of the expanded mass. The resulting structure can be open- or closed-cell. Thus, it can be buoyant or absorbent, depending on the tensile strength of the resin in the liquid state and the post-curing treatment, which may be used to crush the foam and rupture the cells.

The advantages of all foams and cellular structures are their ability to absorb shock and prevent damage to fragile products and their good thermal insulating properties. They are also light in weight with good strength-to-weight ratio, nonabrasive, and easily molded and shaped and offer excellent cushioning and blocking characteristics. Costs vary depending on the type of foam (see Table 16.4 for representative cushionings and costs).

EPS was first produced on a commercial scale in 1943 by Dow Chemical Company, Midland, Michigan. From this modest start, the total output for cushioning of all kinds used in packaging has now reached a rate of 1.5 billion lb (680,400,000 kg) per year in the United States and is valued at about $31 billion. EPS accounts for 1.1 billion lb (498,960,000 kg); rigid polyurethane (RPU), 98 million lb (444,528,000 kg); flexible urethanes (FPU), 80 million lb (36,288,000 kg); reaction injection moldings (RIM), 38 million lb (17,236,800 kg); and a variety of other foamed plastics that include expanded polyethylene (EPE), PE/PS copolymer, expanded polypropylene (EPP) and expanded styrene-acrylonitrile (ESAN), 175 million lb (78.75 kg).

About 60 U.S. firms produce foam board and sheets and/or fabricate plastic foams into cups and hinged containers (363 million lb, 164,656,800 kg), plates and egg cartons (237 million lb, 107,503,200 kg), food trays (221 million lb, 100,245,600 kg), loose-fill cushioning (95 million lb, 43,092,000 kg), and other fabricated forms of cushioning (175 million lb, 79,380,000 kg) [1].

Included in the other forms of cushioning are excelsior (shaved wood), bound fibre (formerly called rubberized hair), cellulose wadding, recycled

TABLE 16.4. Cost Comparison for Selected Cushioning.

Cushioning	Thickness, in.	Cost Range $/ft^2
Bubble sheet	0.125-0.500	0.034-0.056
Cellulose wadding	0.130-5.000	0.053-0.146
Excelsior	NA	0.240
Polyethylene foam	0.031-0.500	0.016-0.229
Polypropylene foam	0.031-0.500	0.016-0.229
Polystyrene foam		
Molded	2.000-4.000	0.200-0.400
Peanuts	NA	0.400-0.460
Polyurethane foam sheet	2.000-4.000	0.400-0.800
Foam-in-place		
0.3 lb/ft^3	NA	0.750
2.0 lb/ft^3	NA	4.000
Uncompressed bound fibre (Rubberized hair)		
Soft and medium density	0.500-2.000	0.320-0.800
Firm density	0.500-2.000	0.540-0.960
Starch-based foam	1.000	0.054
Starch-based loose fill	NA	0.560-0.600
Recycled crimped paper		
2 Cross-stacked pads of 30/50/30 basis wt.	4.700	0.213
80-in. coil or roll of 30/50/30 basis wt.	8.910	0.454

Cost/ft^3

crimped paper, and starch-based foams that are available in both slabs and loose-fill "peanuts."

Packaging engineers can quickly estimate cushioning costs and the effectiveness of each type by referring to the representative cushioning curves in Figures 16.1, 16.2, and 16.3 and the costs in Table 16.4. However, it should be noted that there are many more foam densities and associated costs than those shown. Therefore, before finalizing designs and estimates, complete cushioning tables and costs should be acquired from the applicable vendors to refine the rough calculations.

Polystyrene Foam

There are two types of polystyrene foam, an expanded, rigid open-cell material that is available in the form of slabs and logs and an expandable flexible closed-cell foam that can be molded and extruded into many shapes. The open-cell material is made by injecting a volatile liquid such as methyl chloride into molten PS, which is kept under a pressure of 500 to 1,000 psi (3,447.5 to 6,895 kPa). This can then be extruded as logs or cast into slabs.

More useful to packaging is the expandable polystyrene (EPS), a closed-cell EPS foam developed in 1950 by Germany's Badische Anilin-Soda-Fabrik AG. It is the least costly and most widely used type of foam for packaging and has found application in a diverse array of items including disposable pallets, laminated shipping containers, food trays, counter displays, and, of course, protective cushioning.

The closed-cell material is made from beads of PS impregnated with about 8 percent petroleum ether or pentane. These beads are pre-expanded in a large drum by the introduction of steam at 185 to 205 F (85 to 96 C) to about 25 times their original size and attain a density of 1.0 to 1.6 lb/ft^3 (16 to 26 mg/cm^3). They must be stirred while expanding to keep them from sticking together. The pre-expanded beads are held for several hours until they have stabilized. For molding, EPS is transferred to a mold where steam is injected directly into the cavity through a series of tiny ports in the mold shell. This causes the beads to soften and expand still further, packing them tightly in the mold so that they stick together in a solid mass (see Figure 16.4).

The mold is then cooled with water circulating through the jacket. Since the foam is such a good insulator, it takes some time to bring the temperature down enough so it can be removed from the mold without continuing to expand. A 1/4-in. (6.4-mm) wall takes about 2 min to cool. Heavier sections take proportionately longer. EPS foam is used extensively in molded packaging, particularly for bottles of chemicals, pharmaceuticals, and even living

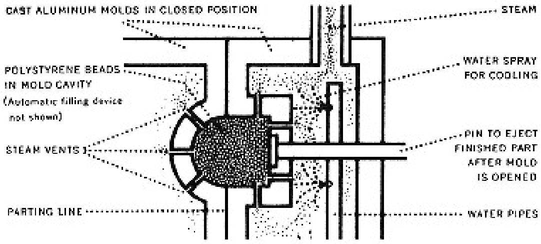

Figure 16.4.
In the EPS molding process, a filling device (not shown) packs beads into the aluminum mold cavity. Steam enters the mold through vent holes causing the beads to expand and stick together. Cold water is then sprayed over the mold to cool the plastic mass, which is ejected from the opened mold by pins. (Source: S. Curtis & Son Inc., used with permission.)

human tissue, since molded EPS containers can be chilled with dry ice for long shipments or simply pre-chilled for shorter deliveries. For reuse, there are metal cases lined with EPS moldings. Molded foam parts also are important in foam block cushioning (see below). For very fragile products, EPS is often molded into lidded boxes that can be lined with convoluted urethane foam padding for extraordinary protection.

A method of making extruded, flexible EPS was developed in Japan in the mid-1950s as a substitute for paper, which was scarce there. Extruded EPS is produced in gauges of 8 to 100 mils (0.2 to 2.54 mm) and densities of 1.6 to 5.5 lb/ft^3. (25.6 to 88 mg/cm^3). Various pastel colors can be made in addition to white, and its characteristic satin finish makes this material very attractive as both a wrap and as cushioning.

A considerable portion of extruded EPS foam sheet is thermoformed, particularly for meat and produce trays. Thermoforming also is used to create cushioning elements such as corner pads. The maximum depth-to-width forming ratio is limited to about 1:2 and, because of the critical softening temperature, it is necessary to use matched molds and a fairly elaborate molding process.

An offbeat development uses heat and pressure to laminate virgin kraft linerboard to both sides of an EPS foam sheet to create insulated RSC shippers for expensive frozen foods. Although used for several years in Europe, American converters were less than enthused about the development until one box maker and a PS producer persuaded food packers of the material's advantages in maintaining lower shipping temperatures for expensive meats, seafood, frozen bakery products, and upscale fruits and vegetables. A PP foam with superior antistatic properties is also made for the packaging of products that can be damaged by static electricity discharges.

A combination of paperboard and plastic is made from an EPS core that is 140 mils thick (3.6 mm). After extrusion and de-gassing, paperboard liners ranging from 26 to 42 lb (11.8 to 19.1 kg) are bonded to the foam core. Total thickness is about that of 200-lb-test C-flute corrugated. The kraft and foam-plastic structure offers 30 percent better edgewise compression strength and equal burst strength compared to traditional corrugated, and the foam/paper sandwich serves as an insulated package with cushioning power. Manufacturing tolerances are very tight to enable conversion on box-plant equipment.

EPS may be used in contact with food, provided it does not contain more than 0.5 percent by weight of unpolymerized monomer [2] and pentane blowing agent residuals do not exceed 0.3 percent by weight of the finished part [3]. However, with fatty foods, even at acceptable levels, the blowing agent may be absorbed and produce off flavors.

Polyethylene Foam

EPE is available as extruded plank and sheet material in thicknesses from 1/8 to 1/2 in. (3.2 to 12.7 mm) or in a moldable grade. Densities run from 2.2 to 9 lb/ft^3 (35.2 to 144 mg/cm^3). PE foam is a low-density, closed-cell, soft, nonabrasive, dust-free, water-resistant cushioning material. It can be heat-sealed or joined with hot-melt adhesives to form bags and envelopes and has a high mechanical and tensile strength.

It is resistant to most solvents and chemicals at room temperature, although strong oxidizing agents may cause degradation, especially at high temperatures. It becomes more rigid at low temperatures and more flexible at high temperatures. The expanded particles do not contain a blowing agent and can be stored for a long time. An advantage of PE foam is that it can be created without additives. Relatively expensive, it is used mainly for upscale products such as paintings and other objets d'art where chemical additives that migrate can cause physical damage.

Polyethylene/Polystyrene Copolymer

A 50:50 mixture of PE and PS is available as a moldable plastic material with great resilience, toughness, and multiple impact resistance. PE/PS resists common solvents and can employ an additive to prevent electrostatic discharge. It can be expanded to a low density of 1.4 lb/ft^3 (22.4 mg/cm^3) but generally is used at a density in the range of 2.0 to 2.5 lb/ft^3 (32 to 40 mg/cm^3). On the negative side, PE/PS requires a blowing agent and the treated pellets must be stored refrigerated and processed within a month.

Polypropylene Foam

About equal to PE foam in cushioning properties, PP foam is available as sheet stock in thicknesses of 1/16 and 3/32 in. (1.6 and 2.4 mm) and in multiply thicknesses of 1/8 and 1/4 in. (3.2 and 6.4 mm). Waterproof and dustfree, it does not support the growth of mildew, fungus, or bacteria. A high coefficient of friction and nonabrasiveness provides good protection to polished surfaces. Density is 0.7 lb/ft^3 (11.2 mg/cm^3). The foam sheeting is made from unstabilized PP and, thus, is vulnerable to ultraviolet light. A few months exposure to sunlight or fluorescent light can reduce it to powder.

Polyurethane Foam

In 1937 a German scientist, Prof. Otto Bayer of Mobay Chemical Corp., discovered the diisocyanate polyaddition process, a completely new way of producing macromolecules. The PU industry has grown out of this technological breakthrough. Its application in packaging has two forms: solid and foam. The solid material is used as a film or a molding material because of its unusual abrasion resistance. PU foams became available around 1945, but did not come into widespread use until 10 years later.

When a polyol is mixed with an isocyanate, there is an exothermic reaction. A certain amount of water is included in the formula to cause foaming. Densities from 1 to 40 lb/ft^3 (16 to 641 mg/cm^3) can be made, depending on the amount of water used. The water reacts with some of the isocyanate to form carbon dioxide, which expands from the heat of reaction, creating the cellular structure of the foam.

Toxic vapors are produced during the diisocyanate chemical reaction that, according to an advisory from the Occupational Health and Safety Administration, Washington, D.C., can cause severe respiratory and eye irritation. Good ventilation in plastics and packaging operations and appropriate respiratory and hand protection are, therefore, advisable. This is particularly true for foam-in-place cushioning, which usually is done in constricted packaging areas.

The original process is being replaced, to a large extent, by less expensive ethers, which are made by a process in which the diisocyanate is reacted with polyoxypropylene. A small amount of water is used in the reaction to combine with some of the diisocyanate to form carbon dioxide. This gas forms bubbles in the gel to make the foam. Catalysts such as dibutyl-tin laurate will accelerate the foaming, and surface-active agents like silicone oil help to keep the pores small. Blowing agents such as methylene chloride supplement the carbon dioxide. The polymerization yields a complicated structure containing, among other things, linkages of urea with ethane, and thus we get the name urethane for this group of compounds.

PU foams are available in a variety of densities and flexibilities, determined by the type of polyol that is combined with the diisocyanate and with the use of either of polyethers or polyesters in the process. Polyethers are used where a low cost is desired. Polyesters give better strength and abrasion resistance. A highly cross-linked polyurethane will result in a more rigid foam than one with a low cross-linked density. Another factor influencing the type of foam produced is the gel strength during the blowing phase, which may result in closed cells and a stiff material or ruptured cells that yield a more resilient foam. The amount of water also controls the amount of carbon dioxide generated and, consequently, the density of the foam.

PU foam is creamy white in its natural state, but quickly turns yellowish brown when exposed to light and usually is tinted to mask this change. Odorless and resistant to oxidation, oils, greases, and fungi, it is affected by strong acids and alkalies, halogens, aromatic hydrocarbons, chlorinated solvents, esters, ketones, and alcohols. Processing equipment can be cleaned with methylene chloride.

PU foam will adhere to any surface that is free of wax and oil. When foamed against a cold surface, a dense skin forms, but if this is undesirable, the surface can be preheated. PU is considered an efficient cushion and will regain up to 90 percent of its original thickness after long standing under load. The polyethers provide a livelier recovery than the polyesters. However, the polyesters are more heat and flame resistant. PU foams will withstand extremes of temperature from -50 to 250 F (-45.5 to 121 C) with very little change, except some stiffening below -10 F (-23 C). A major advantage of PU is that it can be molded in wooden molds lined with film to create shaped blocks. Most other cushioning plastics must use expensive metal molds.

Urethane foam can be made in large slabs and then skived or sliced into various thicknesses. It can be slit, die-cut, hot-wire-cut, or sawed to the finished size. It also can be molded into intricate shapes for special internal packing. In a rather unusual package, PU is introduced between the double walls of pouches, which are then compressed and vacuumized to form a pouch only 0.5 in. (1.3 cm) thick for storage. When the product is inserted and the pouch sealed, the outer film layer is pinpricked to allow air intake and the foam to swell to 3 in. of protective cushioning as air releases the compressed PU foam. In a similar manner, PU can be foamed in place by mixing and pouring two liquid components directly into the shipping container around a film-wrapped product (see Figure 16.5).

Styrene-Acrylonitrile Copolymer

SAN also can be molded into a lightweight, closed-cell, semirigid foam with a smooth, nonabrasive surface. Densities as low as 0.8 to 1.0 lb/ft^3 (12.8 to 16 mg/cm^3) can be attained with two passes through the expander. Like PE/PS copolymer, SAN molding is slower than that of EPS because a hydrofluorocarbon blowing agent must be used for expansion. SAN foam has a shelf life of about six months. Its impressive property is a capability of handling large loadings without problems of compressive set. It also can withstand multiple impacts, superior to the performance of EPS.

Paper and Paper Products

In its many forms, paper is widely used as a loose-fill type of cushioning. Cellulose wadding is an inexpensive form of crepe paper, available in various thicknesses with different backings, facings, and embossings. This material will absorb about 16 times its weight in water and up to 12 times its weight in oil. This is important for shipments since most private surface carriers—the

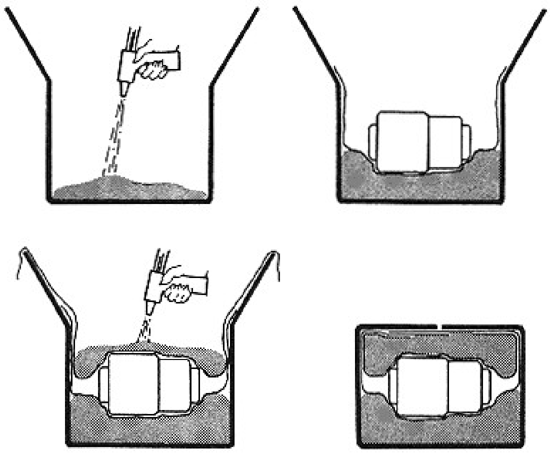

Figure 16.5.
To produce foam-in-place cushioning, a small amount of liquid is dispensed into the bottom of the case with a mixing gun. As the liquid begins to foam, a plastic sheet is placed over it, and the product is put in the center. Another plastic sheet is laid over the product, and more liquid is put on top. The film is then folded over and the box quickly closed and sealed.

U.S. Postal Service and air-transport services, for example—require liquids to be packed with sufficient material to absorb all the liquid in a package.

Old newspapers in crumpled or shredded forms create a cheap source of cushioning material. If a clean sheet is preferred, unprinted newsprint can be purchased. The cheapest sheet material is "bogus" paper. It is made from scrap material and is gray in color. Allied materials are straw and bagasse, the residue remaining from the extraction of sugar from cane, both of which are used to make paper in the Far East and also employed as cheap cushioning. In the United States, wood shavings and excelsior also still are used for dunnage, particularly for upscale products of limited fragility.

An increasing amount of used corrugated and paperboard, now collected in large quantities by both consumers and industry for recycling, is shredded, twisted, and fabricated into a number of cushioning forms. A typical example is made from a variety of recycled papers, which are crimped to form a loose cushioning and fabricated into pads or rolls to put under and around delicate products in single or multiple layers (see Table 16.4).

Corrugated Board

The cellular structure of corrugated fibreboard makes it useful for blocking and bracing, as well as for cushioning. Single-face, single-wall, double-wall, and honeycomb corrugated can be die-cut in different shapes and folded to make spring pads and filler blocks.

Slotted partitions are assembled into nests to provide individual cells for bottles and other fragile items. Corrugated structures also can be used for direct cushioning support in block packaging. However, such applications are limited, because heavy impacts have a tendency to collapse corrugated, and it loses its resiliency under repeated stress. This is indicated in Figure 16.1 by the sharp break in its curve at 0.35 psi (2.41 kPa). For more information on corrugated and solid fibre structures, see Chapter 14, Corrugated Fibreboard.

Molded Fibre

Molded fibre got its start in the early 1900s with egg cartons and fruit trays. But it is the recycling of paper in the 1980s and 1990s that has provided the source material in economic volume to enable this industry to expand into interior packaging cushioning. Suppliers include a handful of large companies, mostly involved with traditional products, and a growing number of smaller firms, which specialize in the custom design and manufacture of interior product packaging, corner caps, and L-shaped edge protectors for product cartons.

The field is competitive, secretive, and lacks both statistics and a formal packaging technology. Many of the machines are custom built by the molders themselves. Design is a matter of trial and error and experience.

Two distinct groups create these new products. One handles large product items and constructions that range up to pallets in size and require heavier molded sections. The product is made by a "slush-molding" process, which is more like papermaking than the plastics slush-molding technique. The second group makes interior packaging for smaller items, usually 10 lb (4.5 kg) or less, and for more upscale products, such as light electronic parts and laptop computers. Thicknesses in these constructions generally range between 0.060 and 0.090 in. (1.5 and 2.3 mm).

The two processes vary in details, but both are basically a vacuum-forming technique and fairly well automated. Most items are made from recycled paper, much of it newspaper stock as well as some other post-consumer waste. Some kraft waste is used where longer fibres are needed in the structure. Density of the molded pulp can be varied, but the cushioning properties are provided more by the inherent design of the part. While the trays, platforms, and inserts created by this process are obviously low in cost, no data are available for comparison purposes and have to be formulated on a design-to-design basis.

Uncompressed Bound Fibre

Originally called rubberized curled hair, this product has not employed hair since the early 1970s and is now made from such vegetable materials as sisal and coconut fibres held together with latex rubber. Uncompressed bound fibre has largely been replaced by plastic foams. However, at least one company still produces it in single-layer sheets from 0.5 to 3 in. (1.3 to 7.6 cm) thick, in laminates to any reasonable depth, and also as custom-molded structures. It is used to a considerable extent in the packaging of military hardware items such as missiles and is satisfactory for products of moderate fragility (see Figure 16.1).

Standard sheets are 72 in. (183 cm) long with widths from 18 to 48 in. (45.7 to 122 cm). Rollstock material is 72 ft (22 m) long in the same range of widths. Special sizes also are available. The sheet material is available in four densities, labeled from Type II to Type V, and ranging in load-carrying capacity from 0.05 to 0.8 psi (0.345 to 5.516 kPa). The molded product is available in densities from 2 to 20 lb/ft^3 (32 to 320 mg/cm^3). A fire-retardant material is also available. Uncompressed bound fibre has an application range from -40 to 160 F (-40 to 71 C), an extraordinary temperature spread for any single type of cushioning.

Excelsior

This ancient cushioning material is said to be enjoying a revival in packaging due to its environmental advantage as a “natural” and biodegradable product made from fast-growing aspen trees, which replenish themselves by generating multiple shoots from the root stock after a tree is cut down.

In packaging, the low-cost, shredded and curly fibres are used as is, nested in a variety of transport containers or sealed into bags to form pads that will not shift during transport. The material is visually rustic in appearance and function, providing a pleasing background for many consumer items, notably wines and fancy fresh fruits. It is now supplied in a host of colors to enhance these values.

The density of excelsior can, of course, be almost infinite depending upon the pressure with which it is compressed in an outer shipping container. For packaging purposes, this should be about 1 lb/ft^3 (16 mg/cm^3) to create a soft bed around the product.

Excelsior also is used in a variety of nonpackaging applications such as pet bedding, target fillings, filtration and evaporative cooling mats, and a number of agricultural applications. Its continued availability, therefore, is seemingly assured.

Starch-Based Cushioning

Spawn of the environmental age are a number of packaging materials, including a cushioning made from grains. The pioneer in this field, launched in 1990, is created from corn, which contains 75 percent of a special starch called Hylon VII. It, in turn, is made up of 70 percent short amylose molecules and 30 percent branched amylopectin molecules. (Ordinary corn starch is approximately the reverse in molecular structure.) The shorter molecules have better cushioning properties (see Figure 16.1).

The cushioning foam is made by heating the starch in a pressure cooker, which turns it into a gel. Release of the pressure and heat foams the gel into loose-fill "peanuts." Residual oil is sold for cooking, leftover proteins and fibre go into animal feed. No petrochemicals or foaming agents are used in the process. When the biodegradable cushioning material is soaked in water, it dissolves.

In addition to peanuts, the corn-based cushioning can be extruded into sheets and planks as well as shaped extrusions such as edge protectors for products and pallet loads. The foam, in 2-in. (5.1 cm) thickness, is capable of cushioning a product of average fragility (see Figure 16.1 for a comparison with long-standing cushionings). On the down side, exposure to high humidities can cause the foam to shrink. Exposed to actual water, it dissolves.

Selecting a Cushioning Method

The choice of suitable packing will depend on the type of item to be packed, its value, and the quantity and frequency of shipment. A single large item of great value will require an entirely different treatment than a large number of inexpensive pieces. If there is a variety of sizes and shapes, it is usually better to work with sheet cushioning that can be used as wrapping and also serve as void fill when crumpled and stuffed into empty spaces in the container. If there are many pieces of the same shape, then a custommolded container or specially designed supports will save packing time. In a high-volume operation, flowable dunnage provides convenience. Although sometimes wasteful of material, it usually makes up for this in labor savings.

The economics of packing fragile objects are often difficult to calculate. It is not enough to simply compare material costs. The labor of packing is often the more significant factor. There is also the question of bulk or cube. This may affect transportation costs and will certainly make a difference in storage space.

Costs of various types of loose-fill packing vary widely, and the price/lb. can be very misleading (see Table 16.4). The total package cost must be calculated including labor and shipping expenses. With replacement of the Interstate Commerce Commission by the DOT's Surface Transportation Board, freight carriers can now set their own tariffs without government oversight, a development that makes investigation of shipping costs more important than ever.

Wrapping and Stuffing

Wrapping and stuffing can be done in a number of simple ways to isolate small objects of reasonable strength from the effects of impact in transit. The most common way is by blocking and bracing the pieces with resilient materials, which will absorb the shock energy and direct it toward the strongest part or parts of the contents. This is sometimes called compression packing and generally is accomplished by wrapping an individual part or parts separately and then stuffing the areas between wrapped objects.

For a single object, a base of cushioning material can be prepared and stuffing can be inserted all around the edges of the product to separate it from the package. A pad of cushioning is then placed atop the item sufficient to create a slight pressure when the shipper is closed.

Plastic foam sheeting ranging from PS to PE and PP in gauges from 1/16 to 1/4 in. (1.6 to 6.4 mm) is one approach. Bubble pack is another (see page 532). Materials such as single-faced corrugated, wadded paper, excelsior, wood shavings, and uncompressed bound fibre also are employed (see Table 16.4).

Free-Flow Cushioning

Free-flow cushioning comes in the form of peanuts, shells, rings, tubes, and spaghetti. Generally created from EPS, in this environmentally conscious age it's also made from foamed starch-based material. The reason for these different shapes is to provide a cushioning material that will conform to objects with different profiles and, at the same time, interlock to form a cohesive mass that will not shift or settle.

In general practice, the packing method is somewhat like stuffing. A small amount of material is put in the bottom of the shipper and items are placed on top with space all around. More dunnage is added until the box is overfilled by 5 to 7 percent or until it takes some pressure to close the container. An airtight container should not be used with foam plastic materials because over a period of time, the blowing agent escaping from the cells could build up a flammable atmosphere inside.

While commonly done, the above technique is not generally the best method for free-flow packing because vibratory action in shipment inevitably causes the heavier product to work its way down through the loose dunnage to the bottom of the package, allowing the contents to rest on the box floor without cushioning.

A better alternative is to loosely fill the free-flow cushioning into sealed PE bags, creating pillows of various functional sizes, which can be packed under, around, and atop a fragile item. If properly sized and placed, the pillows will stay in position and provide superior cushioning for even the most delicate product. The bags will boost costs slightly, but greatly increase performance. If one of the compact bag makers mentioned below is employed, cost is further reduced and versatility increased over the use of pre-made bags.

Another cushioning concept rolls tubes from paper and then crimps the tube in the middle to a right angle. The structure is formed right at the packing station on a very compact machine that produces 3 to 4 $ft.^3$ (0.09 to 0.1 m^3) of flow cushioning per minute (see Figure 16.6).

Figure 16.6.
Paper cushioning made from rolls of new or recycled sheet is slit and rolled to size, then cut off and bent at a steep angle to form loose cushioning that can be made and applied right on the packaging line.
(Source: Patriot Packaging Corp., Cleveland, Ohio, used with permission.)

Bubble Packing

Bubble packing is a sheet created by sealing two webs of PE or PP together, one formed with a series of dimples in the surface that become closed bubbles of air after sealing. The material is available with bubbles of various sizes ranging from 1/8 to 1/2 in. (3.2 to 12.7 mm) in height.

Bubble packing is suitable for many products and in single or multiple layers can handle a broad range of fragilities. It is not recommended for very heavy items, as the bubbles start to break beyond a certain loading. However, a recent switch from conventional low-density PE to linear-low-density has greatly increased the strength of this cushioning.

Bubble sheeting also is used to line envelopes for the cushioning of small items, which are shipped by mail, and the material can be made with an antistatic additive for the protection of sensitive electronic parts and instruments. Recently, a shrinkable bubble material has been introduced by adding a shrink-film layer to the flat backside of the standard bubble sheeting. Introduced in Europe and now available in the United States, the material is generally sealed into a sleeve or bag. After being loaded with a product, it is shrunk to a tight fit in a shrink tunnel or with a heat gun. Initially, it has seen use mainly for furniture and sporting goods.

Compared with other loose-fill and wrapping materials, bubble pack offers several basic advantages: It provides dunnage with a minimum increase in shipping weight and is dust-free, nonabsorbent, chemically inert, and noncorrosive. Like all forms of plastic cushioning, it will not support the growth of mold or mildew. Cost on a weight basis is high, but when other factors such as density, labor, and shipping cost are considered, it provides an economical packaging system, which is very popular.

More recently, at least three machines, two tabletop units from Great Britain and a standalone from Switzerland, have been developed to create larger pillow-type pouches of air in various sizes from webstock on-demand, thus avoiding bulky inventory. Perforations permit separation into single pillows or strips of air-filled pouches. Versatile in application, the strip cushioning can form floors or layers of protection within the shipper, while individual pouches can be stuffed between items.

Suspension Packing

Suspension packing, mostly with hand-assembled constructions, has been practiced in one form or another for many years. Catching attention more recently is an engineered and preformed package that requires less material, stores in very little space, and loads fast.

The structure is basically two knock-down “picture frames” of corrugated board with a window of 8-mil (203-   m) PU film glued across each opening. Product(s) are sandwiched between the film layers and held by the compression and tacky surface of the PU film. The two frames are loaded into a snugly fitted RSC shipper made of corrugated ranging from 200-lb-test (90.7-kg) single-wall E-flute to 275-lb-test (124.7-kg) double-wall B/C-flute. Product weights up to about 25 lb (11 kg) can be accommodated (see Figure 16.7).

A similar concept features a 3-mil (76-   m) layer of metallocene-based PE film tightly positioned around a flat, central panel of 275-lb-test (124.7-kg) double-wall B/C-flute corrugated. Aided by a central score that can be bent to ease product loading, the product is forced under the longer length of film on top of the panel. As the platform is loaded into a standard RSC shipper, end flaps on the central panel fold upward to hold the panel, which rides on Z-tabs folded underneath.

Another new way to suspend fragile items is a double-chambered bag. The product is placed inside the inner bag and the outer bag is inflated via a valve to surround the contents with a total air cushion. Designed for small items, the bags are available in inside dimensions from 5   5 to 10   16 in. (12.7   12.7 to 25.4   40.6 cm). A recent improvement in this container is

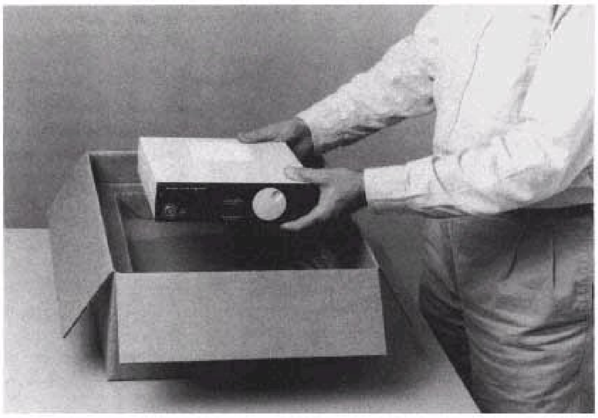

Figure 16.7.
Suspension package sandwiches fragile product between two layers of low-slip resilient film attached to corrugated “picture frames” sized to fit a specific shipper.
(Source: Sealed Air Corp., Danbury, Connecticut, used with permission.)

the addition of a tab on the outer air bag that can be pulled out to deflate the bag, allowing it to be reused a number of times (see Figure 16.8). There is also a special bag for electronic components in which both the inner and outer bags are constructed of two layers of antistat-coated film.

Foam Blocking

Foam blocking made from a variety of resins is a very useful cushioning for products with rigidity and some inherent strength. It is created by cutting molded slabs with a hot-wire knife into blocks and other shapes that fit around smaller products or support corners and/or edges of larger items. Blocks also can be fabricated from honeycomb structures of paperboard and corrugated or molded from paper pulp, generally using recycled materials. Such cushioning should be designed to distribute the load over the largest possible area with support against the strongest parts of the item and clear of the weaker ones.

Figure 16.8.
Double-wall bag inflates in use, deflates, and can be reused.
(Source: Air Packaging Technologies Inc., Valencia, California, used with permission.)

The support area must not be too small in relation to the thickness of the foam or the cushion may buckle instead of compressing uniformly. Generally speaking, a block cushion will buckle if it is less than one-third longer and wider than its height. Overloading also should be avoided. EPS foam has a practical limit of 15 psi (103.4 kPa) for a density of 1.5 lb/ft^3 (24 mg/cm^3) and 20 psi (138 kPa) for a density of 2 lb/ft^3 (32 mg/cm^3). For long storage and high stacking, an additional factor of safety should be used, and the maximum loading should be one-fourth this amount.

Vibration can sometimes be more damaging than impact if the natural frequency of the product is the same as the input frequency of the vehicle in which it is traveling (see Table 16.1). To avoid this condition, select a cushioning material that has a higher natural frequency than the product and the input frequency. The stiffer the foam, the higher the natural frequency. EPS foam with a density of 2 lb/ft^3 (32 mg/cm^3) has a vibration transmissibility of about 80 cps (cycles per second).

Molded Foam

Molded foam can be very effective where a large number of costly products of the same size are packaged and, therefore, warrant the cost of one or more molds to create the foam structures. While low-cost EPS predominates in this field, the more costly plastics described above also have a place, particularly for expensive and very fragile items.

This type of cushioning can range from corner end caps that suspend the product in much the same way as block cushioning to total enclosures that completely nest products, which are both fragile and susceptible to impacts or penetration from several directions. Total enclosures, of course, must be designed for a specific product and size. However, some full end caps can be structured with two or more inner cavities that can slip over products having the same end profile, but which differ in length. Other design considerations are about the same as for block cushioning.

Because of the high cost of molding, relatively inexpensive EPS is usually the material of choice and now the object of an industrial recycling program to collect and reuse the cushioning, which otherwise is cumbersome for local waste disposal systems.

Foam-in-Place

Foam-in-place cushioning is a somewhat more economical approach to the packaging of heavy, irregularly shaped, high-value products. In short labor-intensive production runs, the foam-in-place technique has been very successful in reducing damage and costs. Although this material does not have quite the resiliency of some other cushioning, it is suitable for certain types of consumer, industrial, and military equipment in the range of 50 to 100 lb (22.7 to 45.4 kg).

The process consists of combining a liquid isocyanate with a polyol and flowing the mixture around the product in a shipping case (see Figure 16.5). A plastic bag or sheet is used to keep the resulting PU foam from sticking to the box or the item itself. The formulation can be varied to produce foam from 0.4 up to 2.0 lb/ft^3 (6.4 to 32 mg/cm^3).

The components are pumped from drums through heated hoses to a handheld mixing gun. Some skill is required to dispense the correct amount into the bags or the cavities, and to close the box quickly before the material has fully expanded. Good ventilation is necessary because toxic vapors are produced by the reaction.

Densities range from about 0.3 to 2 lb/ft^3 (4.8 to 32 mg/cm^3) with several intermediate densities from which to choose.

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Chapter 17— Machinery Selection and Specification

General Considerations

In the production of packaged goods, varying degrees of mechanization are required, depending on the type of package involved, the volume, and the diversity of the product line.

Many businesses start up a new product in a small way by hand loading it into its container and, as volume increases, adopting more automated equipment. This may take the form of a simple conveyor belt, individual machines for different packaging functions, or even a sophisticated and integrated assembly machine, according to the needs of the situation. In any case, packaging decisions have to be made, and engineering work must be performed. The following pages are intended to give a few pointers for planning and evaluating the mechanical and/or electronic equipment required for a packaging operation.

With a projected average annual growth rate of 4.6 percent through 1998, the packaging machinery business is thriving. According to the Packaging Machinery Manufacturers Institute (PMMI), Arlington, Virginia, annual shipments surpassed $3.8 billion in 1995 with exports accounting for almost one-fourth of the total [1]. Sales are spread across about 17 categories of equipment with the largest percentages clustered in two areas: (1) conveying, feeding, placing, and unscrambling equipment and (2) coding, dating stamping, and imprinting devices. There are just above 300 members of the PMMI and at least as many smaller companies, including those that specialize in custom machines built to order.

As machinery becomes more sophisticated with high-tech electronic controls and faster speeds, the cost must necessarily go up. Not only does the initial cost increase, but maintenance expenses are higher, and the mechanics, who do the setup and adjustment, must be better trained and paid. It also follows, therefore, that downtime is a much more significant factor with such equipment, and planning and scheduling functions take on added importance.

For many years, the trends have definitely been in the direction of higher speeds, tighter quality specifications, and faster changeovers, which makes it increasingly necessary to do a thorough analysis before committing funds to mechanization.

The Systems Approach

The planning of a packaging line must start with the nature and quantities of the product; the packaging containers, materials, and components involved; and the people, who will operate the system.

As machine speeds increase and lightweight containers replace older, heavier packaging components, the need for an overall coordinated approach to production operations is essential. Incompatibilities of different units in an assembly line may not be apparent at slow speeds, but at high rates, particularly with ultra-lightweight plastic containers, a smooth, uninterrupted flow becomes essential to efficient operation.

Not only must machines be coordinated, but there also should be a good marriage of materials and components that combine successfully in the equipment to form finished packages. This may require some, or a complete, redesign of the package and both materials and shapes may have to be selected more on the basis of machinability rather than aesthetics (see examples in Chapter 9, Glassware, Figures 9.8 and 9.9).

This is why product, packaging, and people are of equal importance. None can be neglected, and all three should be pursued in parallel so that the compromises, which are inherent in packaging systems, can be determined before any one developmental phase is cut in stone.

The end product—the whole reason for being—consists of the product and the package. The ultimate objective should be a production line that controls the container as it moves along, without marking the printed surface, chipping or scratching the container and by restraining each unit at the transfer points to avoid denting or creasing. The line also protects the product from damage and spillage, places the right amount in the package without waste, and seals it to supply the ultimate protection required to maintain product integrity and value throughout storage and distribution.

This accomplishment will improve morale and pride in line performance among workers and foster good housekeeping and adherence to quality standards, all of which add up to a high efficiency. An example of a relatively simple packaging line layout is shown in Figure 17.1.

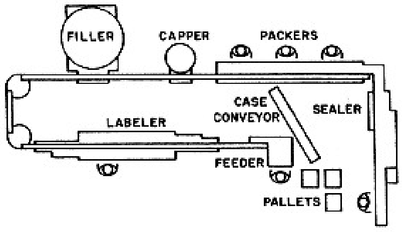

Figure 17.1.
In this typical line layout, bottles in reshipper cases are brought to the line on pallets. The operator dumps the bottles onto the feeder and puts the empty case on the case conveyor. The bottles are labeled, filled, and capped automatically. Packers take the empty cases from the case conveyor and pack the filled bottles. Filled cases are then sealed automatically, and the operator stacks them on a pallet. In this layout, the distance the empty cases travel is minimum, and the pallets are unloaded and reloaded in the same area, for maximum efficiency.

The Product

One of the most important factors in the packaging system is the product, which must be handled: its physical and chemical characteristics, value in relation to other economic factors, and susceptibility to degradation. It is just as important to have a complete set of specifications for the product as it is to have them for the packaging materials. This point may seem elementary, but it is surprising how often it is overlooked.

In the case of dry products, does the density remain constant, or will the equipment have to be adjusted frequently? Variability in density may warrant a weigh filler instead of a volumetric filler. Does the product "bridge" or stick to the walls of the feeder or container? If so, a vibrator is needed. Is it dusty, or does it give off vapors that would require a collection system? Must the product be protected from temperature or humidity conditions or from contamination? Will it be damaged by conventional product-feed mechanisms?

The value of the material may determine whether it would be cheaper to overfill than to pay for a more accurate filling machine. Food products and pharmaceuticals have special problems of sanitation, which also must be considered in the design of packaging machines as well as containers.

It may be desirable to change the product to meet the needs of a higher speed operation or to limit physical characteristics of the product for more trouble-free packaging. Some companies find efficiency can be increased by grading product, that is, separating large pieces from the small and running them separately. Separating granules from fines often will produce a better flow pattern in filling a powdered product and provide a more uniform fill.

If these steps are necessary, then packaging and operations must be included in the product-development loop before the product is cast in stone. This is the time to optimize all elements of product, package, and equipment, a fact that is all too often disregarded.

The Market

It is essential to know how a machine is to be used at the beginning, and what changes in the method of operation may occur in the future. Is the equipment intended for a test market operation or is it to be used for an established product or both? If it is to be used for a limited introduction, can the equipment be upgraded in size and speed or integrated into a full-scale production line at a later date?

To determine these important—and expensive—points, there needs to be some estimate of the initial volume of production as well as the expected demands for the next several years. It is necessary to know not only the initial pack size and product variations, but also any proposed changes that are likely to occur in the requirements of the marketplace. If there is a chance that a sampling program might require a miniature version of the standard package or that a large economy size may be added to the line, it would be well to include this in the original specifications. It may not be possible to predict these changes with any certainty, but the history of other similar products should serve as an indication of what might occur.

Personnel

The degree of sophistication that can be expected in a new production-packaging line may be determined by the skill level of existing machine operators and maintenance personnel and also by availability in the immediate area of people capable of mechanical and electrical/electronic training. It is not wise, for instance, to purchase packaging equipment integrated by an elaborate electronic control system, if current staff does not include someone with electronics expertise. It might be better to choose a less modern mechanical system, which can be adjusted by existing maintenance personnel.

In either case, most machine companies will arrange to train operator and maintenance people in the operation and care of their equipment. This can be very worthwhile, and if such service is available, it should always be included in the plans. At the very least, a lead operator (or all of them) and the head of the maintenance crew should visit the supplier's plant during the course of construction or for the factory acceptance test to learn everything possible about the machine from the people building it.

The Package

The packaging materials must be accurately specified before handling equipment can be precisely defined. The size and type of each component should be carefully detailed in writing, with supplemental drawings and models where necessary. (Examples of the information required are shown in Chapter 6, Folding Cartons and Set-Up Boxes, Figure 6.11, and Chapter 9, Glassware, Figure 9.11 and Table 9.7).

If it is still possible to make any changes in the package that would improve machine efficiency, they should be given serious consideration at this time. For example, the scores of a folding carton might be changed from creased to perforated or cut to reduce the force required for setup and, thereby, minimize the chance of jamming in the machinery.

An overwrap may need to be stiffer or have a calendared surface to suit a high-speed operation. Inks and coatings that might accumulate on working surfaces can be changed or eliminated. The small neck of a bottle, which would have a poor filling rate and might require special nozzles, could be enlarged. A shape that is unstable and would need pucks to keep the containers upright will increase handling problems.

Be sure that the machine builder warrants his equipment to operate with the materials as defined in the specifications.

Storage of packaging materials may be more critical with a faster or more sophisticated machine. Labels should be wrapped in wax paper or plastic film and sealed with tape, not simply fastened with string or rubber bands, to protect them from dirt and changes in humidity. At the packaging plant, storage should be in a cabinet or room conditioned to 70 F (21 C) and 70 percent RH—the conditions under which labels are converted and printed. Folding cartons should be packed in trays that will keep them from warping or losing their prebreak.

When writing specifications, it also is wise to anticipate future changes. There will probably be attempts to economize at a later date by using lighter weight materials and eliminating certain elements of the package. On the other hand, it may become desirable at some time in the future to add extra labels, flaps, inserts, seals, and easy-opening or -reclosing features. All these things should be considered as to whether the current specifications and materials lend themselves to such modifications. While it may not be possible to predict every change that could occur, at least some thought should be given to such contingencies.

The Plant

The conditions at the site often will have a bearing on the configuration that is possible for a packaging operation or even specific machines that can be chosen. Some of the things that can influence this decision are space limitations, available utilities, safety requirements, sanitation problems, and dust or fumes. A thorough study of the proposed location should be made to see that the floor will not be overstressed, and that there is room to bring machinery into the building. If it is necessary to have a supply of compressed air or water or power of the right phase and voltage, make sure that these exist or can be provided. If dust or fumes will be a problem, it may be necessary to plan for filtering or ventilating. If explosive vapors are involved, there must be special blow-out windows and doors along with other safety precautions required by ordinances and regulations.

Selection of Equipment

The quantities of packages to be produced in a given period of time will be a major influence in the selection of equipment. Not only the immediate needs of the production operation, but the projected requirements for at least the next several years should be taken into account. This will largely determine the degree of sophistication that will be required, but it still will leave some room for alternatives.

For example, the economics of a fully automated system can be measured against different levels of semiautomatic production to see which yields the lowest unit cost when capital costs are added to operating costs. Perhaps two slow-speed lines would be more economical than one high-speed line, particularly if several forms of a product or different products must be run on the same line. A three-shift operation might reduce the capital investment that would be required for one or two shifts. Usually, however, a faster machine on a one-shift basis turns out to be the most practical solution and offers increased capability for growth by adding additional shifts when appropriate.

A straight production line is usually preferable to one that turns or doubles back, although sensitive food and drug products may employ a U-shaped line that starts and ends in an outer room to avoid contaminating products with dust and dirt from product and packaging shippers, pallets, and corrugated dust. U-shaped lines also may fit better in constricted spaces and personnel often can service more machines that are closer together than those on a stretched-out straight line (see Figure 17.1).

If such requirements exist, try to avoid dead plates, which increase the stress on packages. Instead, use rotating plates at the turns or miniature rollers that can be power driven. Live conveyors should be used between machine stations. Usually, narrow tabletop link-belt conveyors with links constructed of smooth metal or plastic are used for small- to medium-sized packages and wide-belt live-roller or lug-chain conveyors handle larger containers. Spacing mechanisms—such as worms, helixes, and star wheels—should be made of plastic rather than metal to minimize scratching and scuffing of containers. Steel guide rails also should be lined with plastic bar stock and not a thin tape or film. Some products containing powerful acids or alkalies, such as citrus juices, for example, can destroy carbon-steel packaging machines in a month. For such products, all-stainless-steel machines are the only answer and well worth the high cost of this metal.

There are three general ways of achieving coordinated packaging operations: (1) by balancing and synchronizing the various pieces of standard equipment into a close-coupled, smooth-flowing production line; (2) by developing special equipment that performs a complete packaging operation from start to finish on one machine; and (3) by changing the design of the package to simplify the packaging process and eliminate production bottlenecks.

In the first approach it may be necessary to coordinate the designs of infeed and outfeed devices on each "standard" machine and to interconnect the drives so that starting, stopping, and running speeds are synchronized. Where different machines in the line have different operating characteristics, it may be necessary to provide surge units to absorb fluctuations in container throughput. Although most packaging machines are called "standard," it is rare, indeed, to see a machine that is not tailored in some fashion to suit the specific needs of a particular product and operation. Such machines run from four to six figures in dollar cost, depending upon speed, complexity, and the number of special modifications.

In the second case there are, today, such totally self-contained examples as carton set-up, filling, and sealing units, thermoform-fill-seal or fill-seal tray packers, and the many types of vertical, horizontal/vertical, and horizontal form-fill-seal machines for film pouching and also flow-wrapping. These create the package from bulk material, fill and seal each unit, and deliver groups for loading into the final shipping container. Most run to the low six figures in cost, but some smaller, slower and/or semiautomatic models can be had for four or five figures.

However, for very complex containers with multiple components, which fall outside the range of "standard" packaging equipment, there are special machine companies that build custom-designed straight-line, rotary, or oval machines that perform the entire package assembly, filling, and closing job. Needless to say, these one-of-a-kind machines are expensive, running today from the high six to seven figures in dollar costs. It also should be noted that the first model of any custom machine is a prototype. No matter how good the engineering design may be, the real test is after the machine is put into plant operation. Without exception, the debugging and adjustment period is much longer than that for common machines that have been improved through several generations of development.

An example of the third case is redesign of labeling operations to print variable copy on-demand on-line on pressure-sensitive or thermoplastic adhesive labels, which eliminate the changing of label rollstocks and glue pots and simplify label placement, adherence, and subsequent machine cleanup. Modest in cost, this equipment runs four to five figures.

Another way to establish a functional system is to alter container contours to increase conveyor and machine-handling stability. Where the latter is not possible, generally due to marketing considerations, pucks can be employed to stabilize and orient containers in a manner convenient to the performance of the various packaging machines on the line.

A puck, generally molded from plastic or machined from metal, is a device that firmly holds the product container in an upright position throughout the packaging operation. Container placement and eventual removal can be performed either by hand or by automated pick-and-place devices. The pucks remain on the conveyor system and return to the start of the line on a bypass conveyor usually positioned behind the line. This handling solution doubles the length of the line conveyor, requires considerable expense for the pucks, and necessitates additional clean-up time for both pucks and conveyors. Pucks cost between $25 and $50 each, and the average multi-machine packaging line will require about 300, which must be replaced from time to time due to wear. Obviously, the drawbacks of puck handling make a second look at restructuring the package to make it easier to handle very much worthwhile.

Line Layout

Since plant blueprints usually are out of date before the plant is even completed, be sure to measure the exact room dimensions including ceiling heights and the location of such features as columns, doorways, floor drains, and electrical, air, and water outlets. If the floors are pitched toward drains, note the pattern and depth to determine how and where individual machines must be height-adjusted to create a level line.

Layout prints from machinery manufacturers can be copied, trimmed, and adjusted in size and scale so they can be moved around on the plant drawing to determine the best line layout. Remember that the major operating machines are not the only important line elements. Sufficient space must also be allowed, as necessary, for accumulation or surge stations between connected machines and for machine bypasses to clear the line in the event of a shutdown.

Board of Health or Good Manufacturing Practice rules also may be applicable and must be taken into account, particularly for food and drug products. Machine construction to eliminate points of contamination and ease of cleaning for points of product buildup are now highly regulated. Machines must be built to be easily and quickly disassembled for cleaning and, increasingly, equipped with machine components that help to prevent product mix-ups or misidentification in labeling.

On the human side, the success or failure of a new installation may well depend on the people responsible for its day-to-day operation. It is false economy to skimp on anything that contributes to the comfort and welfare of line personnel, supervisors, and mechanics. Increasingly, the safety factors are mandated by both state and federal regulations.

There should be provision for adequate light, 75 fc (foot candles = 807 lux), in general, and 100 fc (107.6 lux) for inspection areas. Ventilation and temperature should be comfortable. It has been proven that air conditioning in hot environments more than pays for itself in increased productivity.

A low noise level is important not only for sanity, but also for employee safety. The Occupational Safety and Health Administration, Washington, D.C., prohibits continuous noise levels above 115 dB and requires hearing conservation programs at average noise levels of 85 dB or greater over an 8-hour work day [2].

For short lines, emergency stop buttons (E-stops) on each machine, located in prominent and easily available locations, are sufficient. On long lines, a cable E-stop that runs around the entire line and halts all equipment by a pull on the cable in any location is safer, faster, and more convenient.

Good housekeeping; ease of maintenance; convenient access to trouble spots for clearing jams and making adjustments; adequate aisle space; unobstructed, dry and nonslip floors; machines without sharp or projecting objects or points; sufficient overhead clearance and enough space to turn trucks—these investments will build good personnel relationships and lead to better performance and should have an important place in every plan for packaging operations.

It is good practice to keep such key people as line supervisors, union representatives, and maintenance mechanics informed while the project is still in the planning stages. A series of progress meetings will avoid misunderstandings, which could create personnel problems.

The Machine Manufacturer

The choice of a machine supplier ought to be based on past performance in the packaging field, particularly on experience with similar types of products. Although the fine features of a control system or a clever feed mechanism are significant, it is more important to look beyond these mechanical niceties and to examine the manufacturer's reputation. Follow-up on supplied references and, if possible, go and see the machines operating in a production situation.

Examine how the company is organized from the president on down. Inquire about its development programs. These will provide clues to the company's progressiveness and its interest in being competitive. Check into building expansion programs, which can indicate how well the business is doing and whether it will be around the next time you need it.

The supplier of your containers or materials may be helpful in selecting the equipment to handle them. Some of the larger suppliers still have one or more equipment specialists on staff to advise customers in such matters. In fact, some container and material suppliers have even gone into the equipment business themselves in order to improve their services. It is to their advantage to furnish this machinery, if in doing so they can be assured that they will get the major share of the packaging material business. Since the profit potential in materials is far greater than the return on equipment, the supplier may be willing to make some concessions on the cost of its equipment. This aspect should be explored by the packaging engineer.

Whatever the source of machinery, the packaging engineer should thoroughly study the available equipment in the field before making a final decision. He also should take a specification sheet with him to inform the machinery maker about all details of required machine size, utilities, operation, speed, performance, and juxtaposition to other equipment in the line; the nature of all containers and/or materials involved in the operation and their compositions, sizes, and tolerances; and, of course, the nature of the product(s) to be packaged.

If possible, product and containers should be test run at the machinery company. Many builders keep a test machine for just this purpose or will use a machine that is being built for someone else as a test bed. They also usually have a supply of materials or containers left over from previous tests that can be used as a guide, if the final design has not yet been fully determined.

It is, of course, thoroughly possible that some changes in a "standard" machine must be made to suit the applicable container or product. Simple changes often can be fabricated and tried out on the supplier's test bed. More complex changes, though, should be designed and then constructed as a benchtop model—despite the cost—to make sure the idea really works. If done properly, the model will then be installed in the first prototype machine, thereby fully utilizing its cost.

Even with the best communication and the sharing of both requirements and experience, glitches can arise during machine building. The more complex the machine, the more likely this is to happen, but it also can occur with a simple mechanism. For this reason, the packaging engineer should make periodic visits during machine construction to catch these potential problems before they get buried into the system.

During building, the machinery firm also must have a sufficient supply of product and of all the containers, components, and materials that eventually will be run on the machine. It is important that these samples be identical with those to be run in production. Slight changes in dimensions, physical properties, or tolerances can wreak havoc. Enough samples are therefore necessary to avoid running the same containers over and over again, which in itself will cause changes in the packaging. If there is more than one supplier, each should supply an equal amount of packaging for the machine-building program. If, at the beginning, real packages are not available, then models should be constructed that duplicate the real thing as nearly as possible and sufficient flexibility of adjustment should be built into the machine to cover possible future variation.

Well before the machine is finished, a major supply of production packages, components, and/or materials from all vendors should be delivered to the machine builder, which will generally run its own test to make sure the machine is operating perfectly. Then comes the final test, a factory acceptance run by the packaging engineer and as many of the senior line operators, set-up, and maintenance personnel as can be spared from the end user's operations. However, at least *one* of *each* should absolutely be there to learn machine construction and operation from the builder's machinists and field service personnel.

When a multi-machine line is being built by several machinery firms, acceptance testing becomes more complex. Sometimes there is room in the packaging plant to set up the line and then bring all of the machine companies' experts in for final acceptance. The trouble with this approach is that machine modifications or final adjustments are best made at the machinery manufacturer's location where the many machine and special hand tools are readily available. Also, trying to test a new line with a horde of outsiders milling around amid standard production operations can produce chaos.

Better is to pick one of the equipment suppliers (the conveyor manufacturer often has the most space) and set up the line there. Unless the packager is willing to supply its own personnel, “operators” have to be obtained from machine suppliers and temporary employment agencies, the best of all possible reasons for the packager to use its own line and maintenance personnel and train them at the same time.

Final training occurs when the machine or line is installed at the packaging plant and the inevitable glitches caused by machine transport are ironed out by field service engineers from the machinery companies in conjunction with plant personnel. These two joint sessions, with both machinery and plant operating and maintenance personnel working together, will reduce subsequent service calls by the machinery companies about 60 percent, according to a study made some years ago by the PMMI.

Foreign Machines

Since no major industrial nation has a monopoly on good ideas, it is only to be expected that some foreign packaging machines have desirable features not found on U.S.-built equipment. Other countries may even dominate a specific market, such as bar-soap wrappers from Italy, high-speed tray-packagers and wrappers for chocolates from Switzerland, and unit-dose tablet and capsule strip packagers from both Germany and Italy. In some cases, their prices may be lower, their quality extra good, or their technology superior.

However, a number of factors need careful consideration when purchasing equipment from abroad. The first, is to make sure that the foreign firm has a solid base in the United States with good field service and adequate stores of spare parts. The best situation is if it has a U.S. branch office, properly staffed with company experts. If it uses a U.S. distributor, make sure it is a good one, well staffed and highly knowledgeable in the equipment represented. Spare parts can be difficult and slow to get from abroad and service for U.S. installations usually comes after service has been rendered to users in the country of origin and, therefore, can be equally slow.

The metric system used for construction of machinery everywhere in the world but the United States can make parts difficult to duplicate domestically. This also applies to foreign controls, which may not interface with U.S. systems used on the surrounding machines and to motors and other electrical devices that are built for different power systems.

Machine delivery may be much longer from abroad, since working conditions and hours for foreign machinists can be quite different than those here.

Communications are more difficult not only because of the distances and time zone differences, but also from the standpoint of different languages. Therefore, special care in drafting the specifications and purchase contracts is necessary to make sure that not only are the engineering differences covered, but that patents and licensing arrangements are not infringed.

Types of Machines

There is a great variety of equipment available to do just about any kind of packaging job, and choosing the best machine for a particular set of conditions can be a very complex undertaking. Container feeding, filling, weighing, capping, heat sealing, gluing, labeling, case packing, and palletizing can be completely manual at rates to about 25 per minute.

Next in order, there are many types of simple machines available in hand-operated benchtop models or in simple semiautomatic designs capable of about 45 packages per minute.

Then, almost every operation can be handled by relatively inexpensive automatic equipment that runs from 100 to 250 per minute, depending on the packaging function involved.

At the top end of the scale are highly sophisticated machines capable of speed in excess of 2,000 units per minute.

In between are all degrees of auxiliary equipment—conveyors, accumulators, elevators, inspection devices—which also is offered in great profusion. It is not possible in a handbook of this kind to discuss in detail or even to enumerate all of the variations that exist. A great number of directories and even a few computer databases are now available for this purpose.

However, examples of four key operations that exist in most packaging lines will be described here to illustrate some of the many different methods that can be used to solve a particular problem. From this it will be seen that there can be many approaches that will accomplish the same purpose, and it will require some discretion on the part of the packaging engineer to choose wisely from among them.

Feeders

The orientation of containers into a line or a single machine or the placement of a component onto a single container in a packaging operation is a function made complex by the number of existing profiles possessed by such containers and parts. For rigid containers, the dominant technique is an unscrambling operation. Unoriented containers or components are dumped into a rotating bowl and aligned top-to-bottom and end-to-end by air jets or feelers for transfer to a line conveyor or into an applying machine (see Figure 17.2).

The feeding of components also is performed by vacuum-cup devices, which have broad versatility in their suction-cup or finger designs and great speed of orbital rotary pick-and-place action in the feeding of cartons, trays, labels, literature, and other regularly shaped components (see Figure 17.3). There is also a place for the grippers found on robots and other linear arm

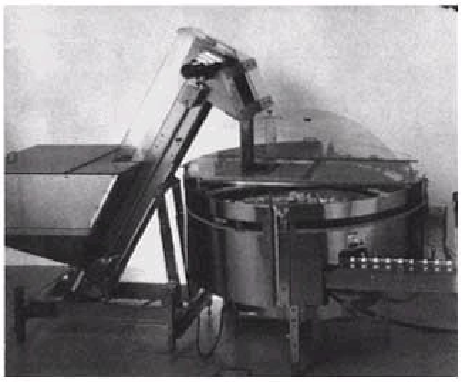

Figure 17.2.
Sortation and alignment of container closures and even small plastic bottles is accomplished by a centrifugal feeder that aligns the objects end to end on a peripheral vibratory track and then upends them onto the infeed conveyor to the line. Speed depends upon the component profile and size of the bowl but can run to the hundreds per minute. (*Source:* Hoppmann Corp., Chantilly, Virginia, used with permission.)

feeders, which can effectively pick up oddly shaped containers and irregular components and product parts, admittedly at lesser speeds.

Included in this category are fixed feeders such as rotary star wheels and timing screws that collect conveyor-fed packages and, by their flighted designs, adjust speed and orientation before introducing the containers into filling, capping, and labeling machines (see Figure 17.4) [3].

On start-up packaging operations, the above feeding functions can, of course, be done by hand using mechanical helpers such as vacuum paddles that pick up a row of bottles from a shipper or pallet load and deposit them on the line. Single-spindle, handheld capping devices, which hold one closure at a time, can effectively seat and tighten caps in very slow operations, too.

Fillers

There are basically two types of liquid fillers, volumetric and constant level, and almost as many types of dry fillers as there are products, but generally divided into six classes.

Constant-level liquid fillers enter the container and fill it to the tip of the filler nozzle with a suck-back action at the end of the cycle to prevent dripping. Constant-level fillers can be constructed with gravity, gravity/vacuum, pressure/gravity, and level-sensing techniques.

Volumetric liquid fillers fill to a precise amount of product, which can cause a displeasing difference of level if container dimensions are not held to a tight tolerance. But these fillers are fast and accurate where expensive

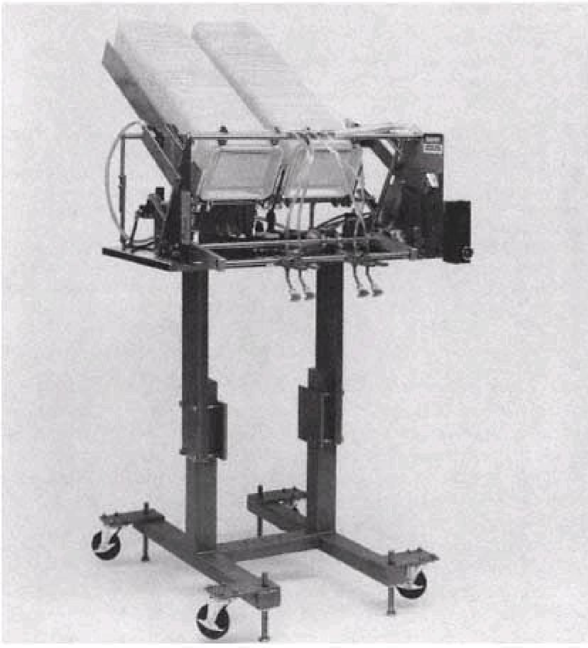

Figure 17.3.
Standalone feeders as versatile as this one can pick and place items as small as a 1 1 in. (2.54 2.54 cm) coupons or pamphlets onto or into rigid containers or cartons. It can also deposit up to 24 30 in. (60.96 76.20 cm) plastic trays on a conveyor for filling. The dual feed cycles at 45 to 60 per minute. (Source: Thiele Engineering Co., Minneapolis, Minnesota, used with permission.)

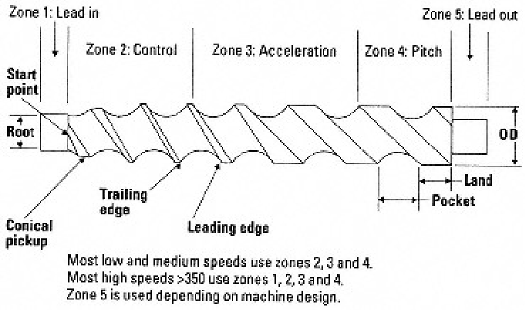

Figure 17.4.
A feed screw collects, transfers and times containers to ensure proper positioning for packaging operations. This diagram of a standard design shows various parts. The root is the smallest minor diameter unless the lead out diameter is less. OD is the largest outside diameter. The lead in is the length of infeed which is equal to the root and in which there is no development of the OD. The start point is the initial development of tooth and pocket. The leading edge is the line where the pocket ends and the land begins, while the trailing, or following, edge is the line where the pocket starts and the land ends. The land is the width at any point from pocket to pocket along the feed screw axis, where the OD is fully developed, sometimes referred to as web, flight width or crest. The lead out is the discharge section where there is no continuation of the OD. (From Packaging Technology & Engineering, October 1994, p. 63. Author: Paul Zepf. Reprinted with permission.)

products demand precise amounts. Their construction can utilize pistons, diaphragms, timed flow, weigh/fill, and auger mechanisms (see Figure 17.5). They also can be designed to fill from the bottom up to minimize the incorporation of air in the product and the development of foam.

Liquid fillers can be either in-line or rotary in action with the in-line units somewhat limited in the number of nozzles they can spread out and therefore the number of containers that can be filled simultaneously. Rotary fillers, on the other hand, have been built with more than 100 nozzles and can attain filling speeds above 2,000 per minute (see Figure 17.6).

For viscous liquids and pastes, the volumetric filler is the only practical method. The simplest liquid filler is the gravity type, in which the supply tank is above the container and a vent tube is put into the container at the proper height to carry off the excess when the liquid level reaches that point.

Constant-level fillers also may be the vacuum type, in which the filling head seals against the mouth of the container and draws a vacuum. This provides the force to bring the liquid from the storage tank; when the level in the container reaches the vacuum tube, the excess is siphoned off and an automatic valve shuts the flow. For faster fills, pressure in the filler bowl may be combined with the vacuum in the container, but this requires more complicated controls.

Flexible containers such as plastic bottles and oblong metal cans cannot be filled under vacuum, because they would be distorted by the outside pressure. A level-sensing filler must therefore be used. In a machine of this type, a stream of low-pressure air passes down the center of the filling nozzle, and when the liquid level reaches the tip of the nozzle, the liquid blocks the air flow, causing pressure to build and actuate a switch to shut off the liquid.

Bottom-up filling starts with the nozzle at the bottom of the container, the nozzle being raised as the container fills. When the nozzle is kept below the liquid level by this method, there is less turbulence, which is important when filling foamy liquids.

Dry fillers can use vibratory product feeding, measure product into a volumetric cup, suck it into a precise vacuum tube, deliver product via an auger feeder, or simply weigh it in automated scale buckets or other types of weighers. The precision and range of these techniques can extend from fractions of a gram to industrial operations capable of filling 100-lb (45.4-kg) bags, 1,500-lb (680.4-kg) pallet bins, or even larger bulk bags.

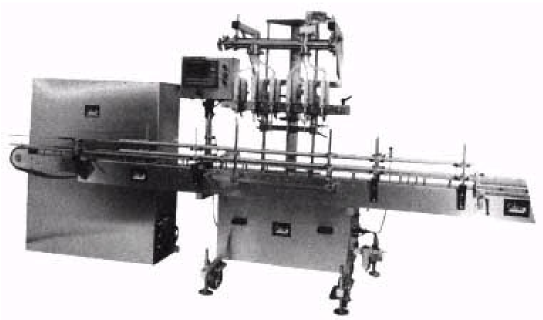

Figure 17.5.
In-line volumetric/gravity filler with five heads (expandable to 10) is ideal for free-flowing liquid products and adjustable for a wide range of fills from microliters to liters. The nozzles are pinch valves with stainless filling needles that can bottom-up fill to reduce aeration or foaming. (Source: Oden Corp., Buffalo, New York, used with permission.)

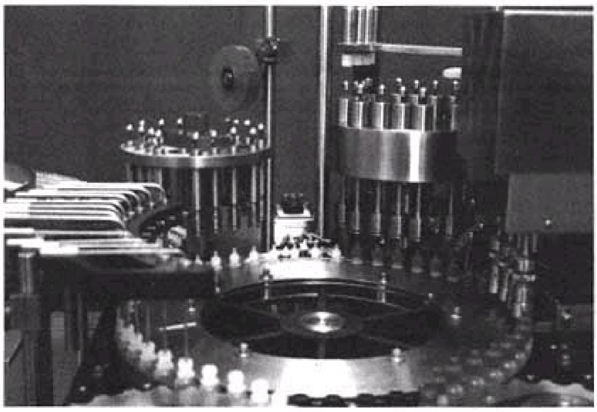

Figure 17.6.
Triple action (left to right) filler, plugger, and capper on a monoblock drive base combines all product and component assembly operations on this pharmaceutical vial machine that can run at speeds of more than 100 per minute, depending on parts design and product consistency. Single drive assures synchronized action of all operations. (Source: Cozzoli Machine Co., Plainfield, New Jersey, used with permission.)

The main problem with filling granular dry products is variations in density. Net-weight filling is the most accurate method for dry products, but has been rather slow.

However, in the handling of dry snack foods, cereals, and the like, which range widely in the weight of individual pieces, multiple weigh buckets are now employed that each contain a portion of the total fill. A computer assesses each bucket and combines those that come closest to the desired weight. So accurate is this system that fill weights can vary less than the weight of a single product element and filling speeds now approach 200 per minute.

Another method is a combination of volumetric and weigh filling in which most of the product is filled volumetrically and the remainder is dribbled in while the pre-tared container sits atop a scale.

Volumetric filling of dry products by an auger or with a rotating plate that has openings of the proper size requires relatively inexpensive equipment and is the least complicated (see Figure 17.7). Vacuum filling can help with light, fluffy powders and especially with hazardous products, although it is slower than other volumetric methods.

With gross-weight filling, the product goes directly into the package, which is resting on a scale. The scale is adjusted to allow for the average tare weight of the container. It is the best method for sticky materials that might cling to the weigh bucket or for products that must settle or be compressed, but it is not quite as accurate as net weighing because of variations in the weight of the package.

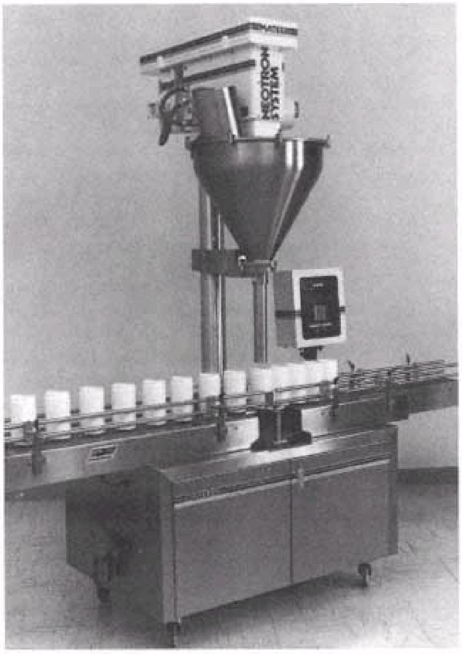

Figure 17.7.
Filler for dry solid products governs portioning by the rotation of an auger located inside the tapered filling bowl. This simple model can be embellished by computer control of auger rotation and integrated tare weighing of containers to sharpen accuracy of net-weigh filling. Speed depends greatly on product consistency. (Source: GEI Mateer Burt, Inc., Wayne, Pennsylvania, used with permission.)

Once again, there are single-nozzle liquid fillers for hand operation and, for solid articles, vibratory sorters that align products in single file for hand packaging.

Flexible Packaging

Numerous machines are available to handle flexible packaging materials. They fall into several general classifications: (1) vertical form-fill-seal, (2) horizontal form-fill-seal, (3) horizontal/vertical form-fill-seal, (4) controlled atmosphere and vacuum packaging, (5) preformed bag fillers, (6) flow wrappers, and (7) overwrappers. The choice of a machine will depend on the type and materials of the package, as well as the characteristics of the product.

If the product is dry and free-flowing, a vertical form-fill-seal machine is usually the best choice (see Figure 17.8). Here, a single web of film or paper feeds down over a forming shoulder that converts the flat web into a tubular shape around the product feed tube with the two sides of the web overlapping. A vertical heat sealer seals these two edges as the material progresses. Product, fed into the tube from volumetric or scale feeders above, falls into the partially formed package, which is then cross-sealed to complete the pouch and severed from the web. The final seal not only forms the closure on the filled package, but also the bottom seal on the next pouch. It should be noted that the cross seals are made through material that varies from two to four thicknesses, the latter in the area of the vertical back seam.

Variations of this package fabrication method now include stand-up pouches that can be made with bottom gussets or flat bottoms, rectilinear, or tetrahedral shapes. Stand-up pouches are increasingly used for liquid products and are being introduced for beverages, primarily to reduce shipping weight and the bulk of discarded containers (see Figure 17.9).

Also, there are a few machines that can insert and seal a dispensing closure into the web of a vertical form-fill-seal machine as it is being formed into a pouch. These are usually relatively large pillow pouches used for institutional sizes of liquid condiments or sauces. Premade pouches with dispensing fitments are used in bag-in-box packaging where even larger pouches for foods and chemicals are enclosed in corrugated shippers or drums.

A vertical machine that accommodates two webs is usually preferred for liquids, however, because all seals are made through only two thicknesses of material and there is less chance of leaks. But two-web machines also are used for free-flowing powders, which are put up in small pouches. In this type of equipment, the two webs are unwound and brought together face to face. Vertical roller sealers form a series of channels in the films for filling by tubes positioned in the center of each one.

Figure 17.8.
A vertical form-fill-seal machine that overlaps a single film web around a filling tube can handle a wide variety of liquid and solid products in weights to 20 lb (9 kg). This versatile model not only makes conventional pillow pouches, but also four-side seal and flat-bottom pouches that stand up in displays and storage. Not in this picture is a product feeder which sits atop the former and can vary from an auger feed to a multi-bucket array governed by a computer that picks the several buckets that make up the closest product charge to the desired weight. Depending on the model, action can be intermittent or continuous with speed in the latter case (the Model VPR, pictured) capable of 80 per minute with a 6-oz (170-g) conventional pouch of a free-flowing product. (Source: Rovema Packaging Machines L.P, Lawrenceville, Georgia, used with permission.)

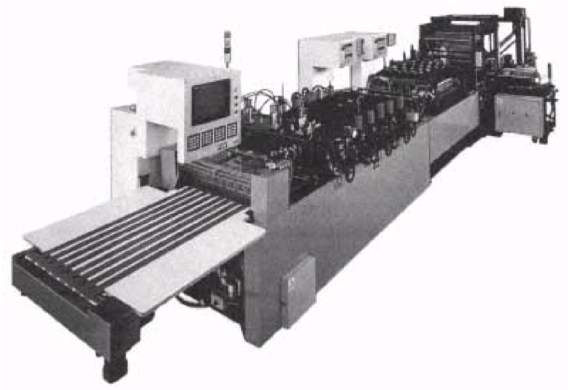

Figure 17.9.
A stand-up pouch with or without a zipper closure is made from a single film sheet on this Japanese-designed twin-lane machine that can deliver 160 zippered pouches per minute or up to 240 per minute without zipper. Action is left to right starting with web slitting and matching, zipper application to the top pouch edge, bottom web seal and then the final zipper crush and side seals.
(Source: Amplas, Inc., Green Bay, Wisconsin, used with permission.)

After filling, and beyond the ends of the filling tubes, a rotary bar sealer extending over the width of the web creates cross-seals to complete the filled pouches. A series of slitting knives can divide the pouches into vertical strips. Cross knives in the rotary seal bar can form horizontal strips or cut individual pouches from the web. Perforating knives can be positioned either horizontally, vertically, or in both directions to create groups of attached pouches, particularly used with small dosage pouches (see Figure 17.10). The vertical pouchers also can vacuum package products by removing air and replacing it with inert gases to increase product stability and shelf life.

Another approach to pouch forming for both dry and liquid products is the horizontal/vertical machine in which a single web is folded upward to make vertically positioned pouches that travel in a horizontal direction through forming, filling, sealing, and cutting from the web. On these machines, pouch packages can be created at speeds to 400 per minute (see Figure 17.11). On a machine with similar actions, small pouches for condiments can be turned out at speeds of more than 1,000 per minute.

For solid products such as fabrics or food slices, there are one- or two-web fully horizontal pouchers. In single-web designs, the film is folded over and the product is inserted in the fold. Folded-web machines can be either fast and automatic or semiautomatic and used with a center-folded film to

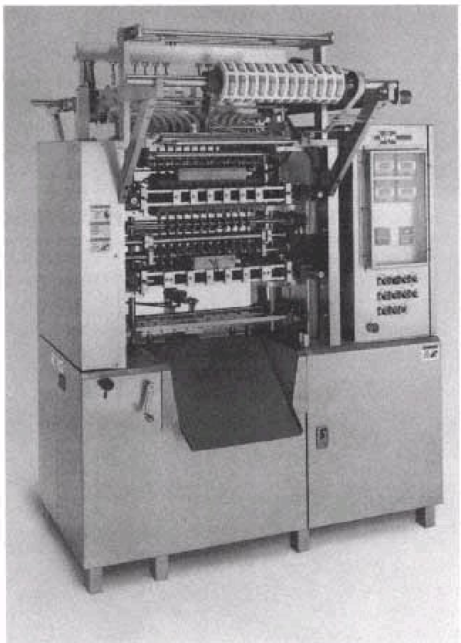

Figure 17.10.
A vertical form-fill-seal machine that creates four-side seals in twin flexible webs up to 25 in. (63.50 cm) in width can handle liquid or granular products at speeds to 1,500,000 pouches per three-shift day in sizes from 0.05 to 6 fl oz (1.5 to 177 ml). (Source: Winpak Lane, Inc. San Bernardino, California, used with permission.)

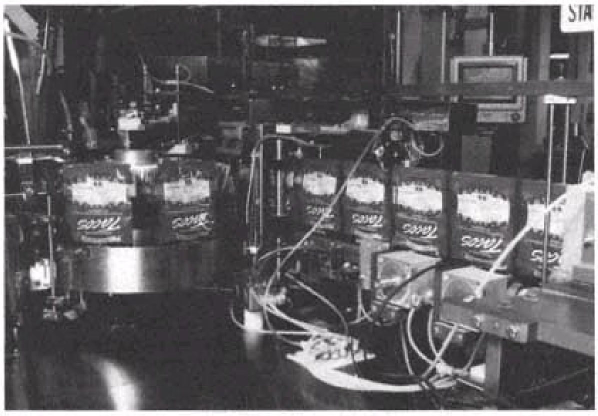

Figure 17.11.
Form-fill-seal machines that fold a single web into vertical pouches that travel horizontally through filling, sealing, and cut-off are also now equipped to apply reclosable zippers on machine. Rotary filling/sealing action enables outputs to 100 per minute.
(Source: Klöckner Packaging Machinery, Sarasota, Florida, used with permission.)

package a host of relatively flat products at moderate speeds (see Figure 17.12). Two-web machines where the top web is brought down to meet the bottom after products have been placed in position are automatic and relatively fast.

In addition to the horizontal machines for this purpose, there are also a couple of vertical machines that are very economical in floor space and enable the products to be tossed into the opening in a center-folded sheet of film, which is then indexed downward to close the side seam and cut off individual packages.

Still another type of horizontal pouching machine, called a flow wrapper, makes a pillow pouch in continuous motion. It is widely used for high-speed packaging of confections, as well as other large-volume food and nonfood products.

Preformed bags or pouches are higher in cost, but in some circumstances, using these ready-made packages is most practical. Premade bagging may be the answer if volume is moderate, the speed of the operation does not warrant automatic equipment, there are constant changes in products, or the nature of the product does not lend itself to sophisticated machinery. There are a variety of inexpensive bag feeders that index a single bag into a filling station, open it with an air blast for hand filling, and then seal the bag top. There are also rotary machines that contain a number of stations and automatic bag feeding that can be used for either manual or automatic filling at higher speeds.

Case Packing

The unitizing of product packages at the end of the line can be accomplished in a number of ways. Most usual is the placement of small- to medium-sized unpackaged or packaged products into corrugated cases. These may be reshippers, which arrive at the loading point already erected after depositing empty containers at the head of the line or knocked-down blanks, which are stacked in the magazine of the case packer and erected just prior to loading.

Depending on the volume of output, the entire setup, fill, load, and closure of corrugated packaging can be handled in a single machine (see Figure 17.13) at speeds to about 35 cases per minute, followed by an automatic taper or gluer and an automatic label printer/applicator that can apply a long label around a side and end of the box. This gives the two-panel identification needed by shipping people to spot codes regardless of the case orien-

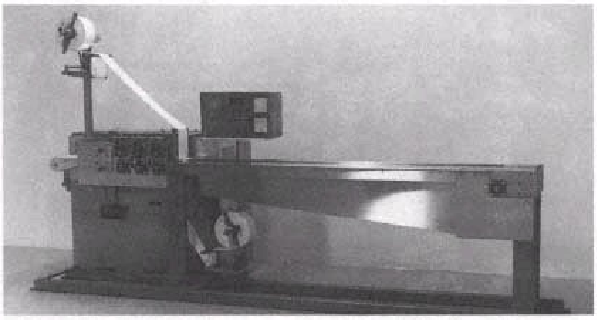

Figure 17.12.
Horizontal pouching machine that operates with twin webs from 6 to 12 in. (15.2 to 30.5 cm) wide can be either hand loaded or fitted with automatic feeders. This unit accommodates just about all heat-sealable and cold-seal flexible materials, which can be printed or plain. Speed ranges from up to 45 per minute for manually placed and normally low-profile products. (Source: Wrapade Machine Co., Inc., Saddle Brook, New Jersey, used with permission.)

tation on a pallet and in warehouse storage. New electronically controlled case packers permit very fast setup for different packaged goods and shipper sizes.

If output is a bit slower, the shippers may be set up and filled by machine, but closed and labeled by hand. One person, assisted by hand devices, can handle 15 to 20 shippers a minute over a complete shift, depending on product weight. Still slower operations can be operated from a compact machine that sets up the shipper for hand loading, closing, and identification, usually a two-person team operation (see Figure 17.14).

Increasingly, however, products sold in high volume to retail outlets are loaded bare onto pallets with tiers separated by plastic or paperboard slip sheets, which often are reusable. Angle-shaped fiberboard or plastic protectors at the corners of the pallet help keep containers in line and stretch-wrapped film holds the load together. This system also is used to ship high-volume empty product containers to packagers. A variant is to use shallow

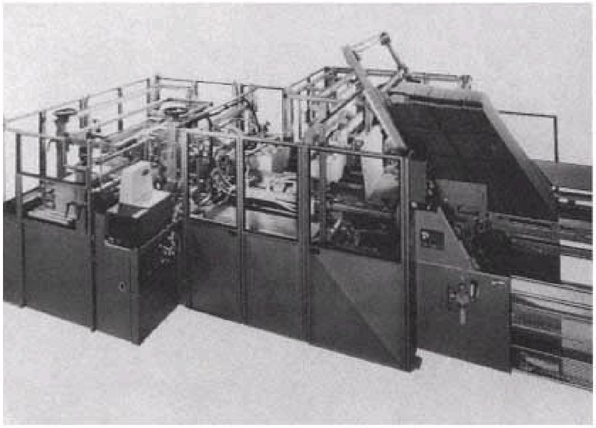

Figure 17.13.
Fully automatic case packer is capable of speeds to 35 or more shippers per minute depending on product and case or tray sizes. Three models accommodate case sizes from 6 2 5 in. (15.2 5.1 12.7 cm) to 24 16 30 in. (61.0 40.6 76.2 cm). Action is from right to left as KD (knocked-down) shippers or trays are fed from a magazine to the erector section, filled, and sealed. The high-volume machine needs only occasional operator attention.
(Source: R.A. Pearson Co., Spokane, Washington, used with permission.)

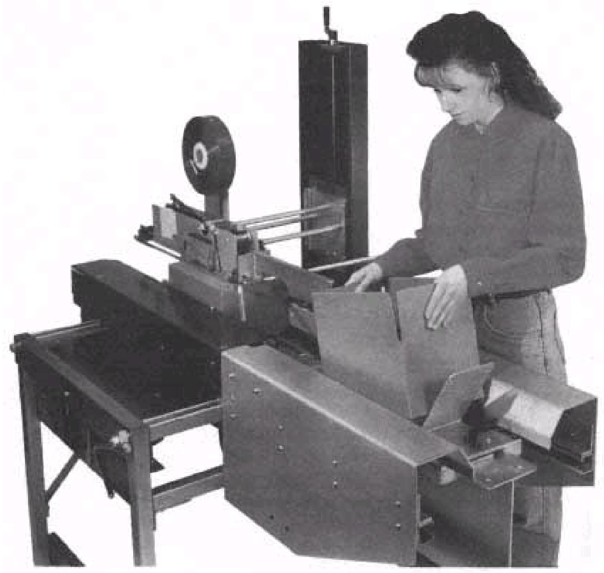

Figure 17.14.
Semiautomatic case packing for low volume products has automatic erector platform to close the four bottom flaps. Operator then loads the products and nudges the shipper into an auto-taper that seals both top and bottom flaps. The action minimizes the stress in this normally tiresome operation.
(Source: Durable Packaging Corp., Chicago, Illinois, used with permission.)

trays to hold each tier of containers, with the load stretch- or shrink-wrapped. These systems can range from manual to completely automatic in action.

Machine Ordering an Scheduling

Financial Analysis

Before purchasing any equipment for the packaging line, it is generally necessary to make an economic study to see whether the expenditure will be justified. This entails an analysis of all the expenses involved, balanced against the savings that will accrue by the elimination of hand labor. Some of the items to be counted as cost factors include:

(1) Base cost of the machine

(2) Interest, or loss of earnings on invested capital

(3) Increase in taxes

(4) Insurance

(5) Depreciation

(6) Floor space

(7) Extra attachments

(8) Change parts

(9) Replacement parts

(10) Engineering

(11) Travel and communications

(12) Machine design changes

(13) Package redesign

(14) Tighter material specifications

(15) Delivery

(16) Installation

(17) Debugging

(18) Materials for testing

(19) Maintenance

(20) Supervision

(21) Training of mechanics and operators

(22) New operating personnel

(23) Downtime for malfunctions and changeovers

(24) Scrap losses

(25) Added inspection

When all these factors have been considered and evaluated, and the total cost is spread over the required number of years, it must be compared with the real savings that will accrue. For each operator that is eliminated as a result of mechanization, there will be a saving in salary plus some overhead costs. Not all overhead costs can be dropped. A certain amount of the fringe benefits and supervision will be eliminated, but heat, light, and other building costs will continue just the same. Among the items that can properly be included in savings are the following:

(1) Salaries

(2) Fringe benefits

(3) Supervision

(4) Washroom space

(5) Parking space

(6) Bookkeeping

(7) Administration

(8) Machine resale value

(9) Tax savings

(10) Quality improvements

An important decision is the length of time to be allowed for amortizing the cost of the equipment. This varies with different companies and situations. The average length of time for most companies is about three years. This means that if a machine will not pay for itself within three years, it is not considered a good investment. In some cases, today, two years is set as the time frame for payout. If the product is new, and its chance of survival in the marketplace is questionable, it might be safer to figure on a one-year payout, particularly if new equipment is going to be quite expensive.

On the other hand, if the product is well-established and there is little likelihood of a change that would obsolete the equipment, it might be reasonable to amortize costs over a longer period. However, in today's fast-moving markets, considerable caution should be used in opting for long-range payouts.

Since capital costs can be taken from taxable income, it is sometimes said that machinery can be bought with 54-cent dollars. While this may not be entirely true, since depreciation is a diminishing factor, there is some justification for shading the costs to reflect a fair amount of the tax benefits. The tax rate for most corporations is around 46 percent of profit. Depreciation of a machine can be charged to operating expense, so that for each dollar deducted from taxable income, there is a saving of 46 cents in taxes. Both the tax credit and the fast write-off provisions of the tax law should be taken into account in calculating these savings.

There may be other extenuating circumstances that would weigh in favor of buying a piece of equipment, even when the dollar figures do not appear to justify the expense. Such things as better housekeeping, improved quality, a different type of package, or a shortage of labor may be quite valid reasons for investing in a new machine. There may even be such reasons as a desire for a showcase operation, a shortage of washrooms, or a lack of parking space that would swing the balance toward mechanization of an operation. These are all perfectly good arguments and not to be taken lightly.

Total Cost of Equipment

The real cost of owning equipment is more than just the purchase price plus the operating costs. The fact that capital is tied up instead of earning interest in other investments must be taken into account. Also the variable character of the different elements that make up the total figure should be considered. They are not usually straight-line functions, but have a changing rate, which makes it difficult to break them up into nice neat pieces. Thus, it would be incorrect from an accounting viewpoint to amortize a new machine at a steady rate over a specified number of years. Since capital costs decrease with time as a result of diminishing interest charges, and operating costs go up as maintenance and replacement costs increase, there is a variation in costs with time.

A recommendation to purchase a new piece of equipment may be perfectly justifiable from an engineering viewpoint, but unless it is presented to management in the right terms, it will risk being rejected as a poor investment. While it is not necessary to understand all the intricacies of accounting procedures, it helps if a packaging engineer can use the methods and terminology of the accountants so that he can more easily relate a proposal to current investment plans.

There are several ways to evaluate proposals for new equipment. "Payout" is a method for measuring the time required to recover the original investment. It is a quick, easy gauge for measuring the risk involved, but it has certain disadvantages. It does not allow for earnings beyond the recovery period; it is not related to any minimum acceptable rate of return; it does not take into account the time value of money; and it cannot be related to other investment opportunities.

Another method for evaluating requests for capital funds is the "return on investment," either the return on gross investment or the return on average investment. The first uses gross investment as a divisor, and the second takes half the depreciable assets as the divisor. In either case, the annual earnings are related to the investment over the expected life of the equipment. The "expected life" is where the calculations can go astray, because the value of earnings that can be reinvested is ignored, as is the compounding of interest. Return on investment must be calculated from increased productivity and reduced cost of product, package, handling, transportation, and marketing.

There is also a "discounted cash flow" method of calculating the costs of equipment. On this basis, an investment must generate enough additional profit or savings to recover the original capital plus a certain minimum return in earnings. This becomes difficult to calculate when the cash flow in each direction occurs at different times, although compound interest tables can be used for present values and a reciprocal table for future values.

Whichever method is used for figuring the cost of equipment, it is necessary to combine the capital cost and the operating cost to get the full cost of ownership. Figure 17.15 shows how the declining capital cost is added to the increasing operating cost to get a combined total cost figure. In this example, it reaches its lowest point at about the fifth year. This may not be the end of the equipment's economic life, since replacement cost will be somewhat higher than the lowest point on the curve, and this extends the useful life of the machine another four years in this case. It is not essential to work out this cost curve with any degree of accuracy, it is only necessary to know that it exists, so as not to put too much emphasis on a straight-line payout plan.

A piece of equipment loses its value with age, so that all or part of the original investment is lost. What remains of the original value at any point is called the "salvage value," an amount that can be realized by sale or trade-in. A method of prepaying this loss out of the return on investment by "depreciating" the original value according to some standard formula yields a "book value," which declines with time.

There are several ways of calculating depreciation: (1) the straight-line method, in which the equipment is half depreciated in half its useful life; (2) the sinking-fund method, which takes into account the salvage value of the equipment and gives a half-life depreciation of about 40 percent; (3) the double declining balance, which depreciates the value by two-thirds at the halfway point, and is the most popular method; and (4) the sum-of-the-integers method, in which the equipment is about 75 percent depreciated in half its expected life.

Note that interest should be charged also on the undepreciated balance,

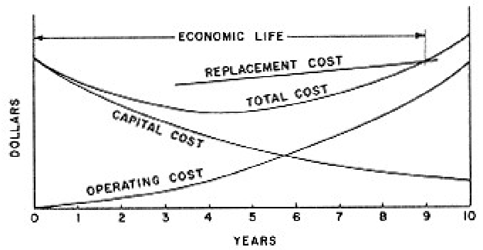

Figure 17.15.
As capital cost is depreciated, operating costs tend to go up, although not usually in the smooth curve shown. The full cost of ownership is the sum of the two, which is shown as a total cost curve. When this becomes greater than the replacement cost, it is time to get a new machine.

since this money could be earning a return if it were invested elsewhere. The effect of taxes on capital investment must be taken into account. In a growth company, where the payment of dividends is not in proportion to its profits, a fast write-off is desirable. If the funds that are made available in this way are reinvested in other improvements, taxes can be deferred in proportion to the continued rate of reinvestment. On the other hand, if increased profits are anticipated in the future, it might be better to defer depreciation by using a straight-line method of accounting. The tax rate for a typical corporation is about 46 percent of profit. Depreciation is charged to expenses, not capitalized, so that 46 percent of the deductions for depreciation that would normally be paid out in taxes can be retained. Net interest costs can be deducted in their entirety. These are not so significant as the savings that are made in write-offs, and since interest is charged against the book value of the equipment, it is a diminishing credit. One of the side effects of tax write-offs is to shorten the economic life of a piece of equipment. Not only does it reduce the time it takes to reach the low point in the annual total cost and the annual average cost, but it reduces the replacement cost and moves the crossover point in Figure 17.15 toward the left.

Buy or Lease

There are many companies, both large and small, that prefer to lease rather than buy packaging machinery. If the product is standard and expected to have a good future, outright purchase is undoubtedly the best choice. The tax benefits and the opportunity to make alterations to the equipment weigh heavily in favor of outright purchase.

In some special cases, however, it is more prudent to rent a piece of machinery or even a whole production line. The conditions which favor leasing are: (1) products of uncertain future; (2) new and unproven machine technology; (3) one-time promotions or other short-run situations; (4) supplemental equipment for seasonal or peak demands; (5) government contracts, which allow full write-off of the rental cost; and (6) shortage of capital or lack of approval by top management.

Some companies have a rule of thumb that if the purchase price is less than the cost of a five-year lease, they will buy it outright. Otherwise, they favor a rental arrangement. This is particularly true in industries where rapid changes in packaging could make a machine obsolete in a short time.

Lease-purchase agreements are the most common type of arrangement. Under this plan the user pays a fixed rate per month or per year, and at the end of a specified period either owns the machine outright or can buy it for a nominal sum. The tax benefits under such a plan are limited to the amount paid at the end plus the interest portion of the rental charges. In a direct purchase, the entire amount can be written off.

Other leasing plans include: (1) quick-termination contracts that can be paid up at any time; (2) decreasing payments and a nominal rental after a certain number of years; (3) the "evergreen" type of decreasing payments with no definite termination; and (4) "humpback" contracts that increase the charges to coincide with anticipated sales curves.

Some machinery manufacturers prefer to turn over leasing contracts to a finance company. There are a number of leasing corporations that will handle these financial arrangements. The charge for this service is about 5 percent added to the prime interest rate.

There is an important difference between a rental arrangement and a leasing agreement, which should be understood. A rental is usually for a short period and can be terminated at any time, normally without penalty. A lease is for a longer period, sufficient to pay the total cost of the machine. If the lease is terminated before that time, the lessee is obligated to find a buyer and to make up any difference between the sale price and the balance of the lease agreement.

Contracts and Specifications

A good workable set of specifications is the purchaser's best assurance that the machinery he buys will fit specific production line requirements and deliver trouble-free performance. These specifications must be complete and accurate and should do the following:

(1) Define clearly the purchaser's basic requirements and any special needs, which may be occasioned by such things as safety, sanitation, dust, or explosion hazards.

(2) Determine what is "standard" with the vendor, and set forth what is acceptable as substitutions or deviations.

(3) Provide the manufacturer with mechanical and electrical information to eliminate any need for guessing or assumptions about conditions at the site.

(4) Establish a plan for testing, acceptance, and subsequent handling of complaints for both the vendor and the purchaser.

(5) Provide legal protection for both buyer and seller, and define ownership of new design and patentable ideas.

(6) Inform other departments concerned, such as maintenance, production, purchasing, and plant engineering.

(7) Provide a permanent record for purposes of reordering.

It is imperative to put into writing all the details that have been agreed upon and the understanding of exactly what is to be furnished, and when, and how. It is particularly necessary to know what the manufacturer furnishes as standard on his equipment and to spell out those additional or special features that the packer requires to meet his particular needs. It is in this area that most of the misunderstandings between buyer and seller occur.

Special features often add considerably to the purchase price, simply because such extras take a great deal more engineering and fabrication time. The design cost of the basic machine can be spread over many units, but a custom-made attachment must absorb all the one-time costs.

One area that should be carefully detailed in the purchase specification is the electrical wiring and controls. This can include such things as types of enclosures, code markings, cables and harnesses, and location of components. Use brand names in writing specifications only when these are a part of company specifications to standardize mechanical and electrical/electronic parts. In general, it is better to describe the required operational characteristics and let the machine builder choose the items that have worked best in the past.

Product-handling areas that come into contact with abrasive or corrosive products should be noted. The same goes for areas that require steam or other special cleaning methods. These product factors may require special materials of construction. Guards should be required in areas where there are heaters, moving parts, pinch points, or electrical connections.

Changeover methods should be spelled out. Some machines have a choice of change parts for on-machine adjustments. Many such changes, today, can be handled by electronic control systems that, at the touch of a button, can adjust guide rails, turn handwheels, and slide collars into position. Which method to use should be given considerable study and then specified.

Drives require explanation. First, it must be decided whether drives must be synchronized with other machines, and then whether this should be done mechanically or electrically. Some allowance should be made for declutching in case it becomes necessary to hand-feed a machine while it is being worked on. It is a good idea to specify variable-speed drives so that any hand work on the line can be paced to maximum efficiency.

Lubrication systems should be covered. A central system is usually preferred, but any method that is convenient for the operator to manipulate on a routine basis should be satisfactory. If the system is too difficult to operate, the machine may suffer from lack of attention.

Safety controls, such as interlocks or overload and jam switches, which will automatically stop the machine in the event of a malfunction, will prevent damage to the machine and minimize downtime.

Fill control will have an important effect on the cost of product for the life of the machine. It is essential that the allowable tolerances be spelled out, and that the amount of scrap be kept to a minimum.

Label placement and cap tightening torque are other details for which tolerances should be fixed when drawing up a contract.

The availability and terms for field service and repairs should be determined and made a part of the purchase contract. Training of personnel also should be part of the agreement, as should the initiation of a maintenance program. A complete set of blueprints, a parts list, and an acceptable number of operating manuals must be included. Most machinery companies specify a kit of vital spare parts that should be maintained by the user. These should be spelled out, if not indicated, as should the spare parts that the builder will maintain in inventory and those that are subject to special ordering.

Security or secrecy agreements, which bind the seller not to disclose to outside sources any information regarding product, package, or machine, are increasingly a way of life, today, and often submitted to each other by the user and the machinery company, both of which have sensitive data to protect. Normally signed at the beginning of negotiations, it is important that the duration of secrecy be defined and that the period of exclusive use of special designs be included where applicable. See Table 17.1 for a checklist of items that should be included in the purchasing contract.

Scheduling

The target date for getting new equipment into production may be determined by a need to meet competition, by the introduction of a new product or variation of an existing product, or by a demand for quantities that are beyond the capacity of the existing facilities. It is very possible that the start-up date will be the most important factor in the selection of packaging equipment. If one type of machine is available sooner than another, this could easily become the deciding influence in the final choice.

This promise date of the manufacturer is the starting point for setting up a schedule. The average delivery time for standard equipment is 5 to 7 months. For special or customized designs, it is more likely to be 12 to 15 months. To this must be added the time required for crating, shipping, uncrating, and moving the machine into place.

There is usually some wiring and piping to be done, and perhaps some carpentry or masonry work. Some of this can be finished prior to delivery, if there is sufficient information, but it would be safer to figure on at least a week for installation, after the delivery date. Some alterations may have to be made to the equipment after it arrives—either planned changes to suit the conditions on the site or corrections that become necessary in matching

TABLE 17.1. Purchase Contract Checklist.

BASIC MACHINE

Name and model

Materials of construction (corrosion-resistant, etc.)

Right- or left-hand operation

Utilities

- Electric current (phase)
- Air (pressure)
- Water (temperature)

Drives and controls

- Motors
- Starters
- Safety switches
- Sensors
- PLCs and/or computers

Lubrication system

- Automatic
- Centralized

Appearance

- Guards
- Paint
- Plating

Auxiliary equipment

- Counters
- Heaters
- Indicators
- Clutches

CHANGE PARTS

Quantity

Interchangeability

Marking

TERMS of CONTRACT

Price

Rate of payment

Delivery date

Method of shipment

Demonstration on line

Test period

Defective workmanship

Defective parts

Service

OPERATIONAL GUARANTEE

Speed

Packaging materials

Tolerances

Operators required

- Number
- Skill

TABLE 17.1. (continued).

ACCEPTANCE CRITERIA
Length of runs
Number of changeovers
DATA FOR INSTALLATION
Weight
Electrical load
Certified drawings
Wiring diagrams
Operating manual
Lubrication and maintenance data
SPARE PARTS
Maintained by user
Maintained by manufacturer

a machine to other components in a production line. An extra week is not too much to allow for such contingencies.

Then there is the debugging period. There is scarcely ever a piece of equipment that functions properly the first time it is turned on. If it is a “standard” machine, which is identical to a number of other machines, the chances are good that it will take only a couple of weeks to get it operating at peak efficiency. If it is a one-of-a-kind machine, custom-built for a special purpose, it may take many months before it reaches its rated speed and is functioning as intended.

A critical path or PERT chart is very helpful in keeping track of the entire event—from building to final successful operation—so that pressure can be applied in the right place and, if a delay is inevitable, the affected people can be notified at the earliest possible moment. If all the preliminary work is carefully done, and a reliable manufacturer is chosen, the chances are good that the final results will be satisfactory.

As line speeds increase and machines become more complicated, the need for careful planning becomes more acute. As long as an orderly consideration of all the factors involved is started early enough, if the contract and specifications are written to cover all points, and a complete understanding is established between the various parties concerned, both the buyer and the seller of the equipment can be assured of a profitable and successful venture.

In calculating the output of a machine, do not neglect the factor of downtime. When a piece of equipment is shut down for adjustment or lack of supplies, the operating personnel are still being paid, in most cases. If the reliabilities of all machines in a line are calculated at 98 percent and the line consists of four machines, the reliability of the line, as a whole, is the fourth power of 98 percent or about 92 percent.

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3. Zepf, Paul J. 1994. "There's More Than Meets the Eye in Timing Feed Screw Technology," *Packaging Technology & Engineering,* (October):63.

Chapter 18— Preshipment Testing

Introduction

An essential part of any packaging program is the testing and evaluation of the completely packaged unit, as well as its various components, to determine its ability to withstand the rigors of transport, storage, and handling. It is an essential, however, that is often ignored by packagers, who report that they do not get any significant number of damage reports from customers, and/or it is cheaper to send a new item to a customer than it is to beef up the whole product package, which many company managements already regard as excessively expensive.

Investigation usually uncovers the fact that customers originally did complain and, when no action resulted, gave up complaining as a waste of breath or changed to a different product. Many packagers leave packaging selection up to the purchasing department or their vendors because they have no competent packaging technologists on staff to design and test product packaging. These sources often give principal attention to packaging cost complaints from management, even if they know that container strengths are being whittled below safe levels.

This situation is now doubly dangerous because customers of all kinds are more particular about quality; competition, particularly from lower cost manufacturing areas of the world, is increasingly fierce; and regulations for those products subject to government oversight are becoming increasingly stringent and costly.

Therefore, it is only good economics to create optimum packaging designs. In fact, for a new product that has no performance history, it actually makes good sense to overdesign the package to ensure it will provide total protection. Marketing managers want users to evaluate only the product and its performance. However, if the package fails, the consumer has the opportunity to make two judgments for not repurchasing and marketing may never know whether it was the product or the package that did not make the grade.

A good test program will indicate the results to be expected for all product and packaging components in the field, and it will yield dividends far in excess of its cost. If the product succeeds, the packager has a product lifetime to pare down packaging costs as technology improves and the optimum design is reached. Good management demands an objective evaluation of every step in the packaging operation.

Even the simplest product has primary and even secondary and tertiary containers that should be evaluated. The components of these containers also have test procedures that should be performed by their manufacturers and/or the final packaging manufacturer. In fact, the Fourth Edition of *Selected ASTM Packaging Standards* contains 123 standards and procedures for packaging (see Table 18.1). In addition to these tests, promulgated by the committees of the ASTM (American Society for Testing and Materials), West Conshohocken, Pennsylvania; there are additional tests and standards developed by the International Safe Transit Association (ISTA), East Lansing, Michigan; The Technical Association of the Pulp and Paper Industry (TAPPI), Atlanta; the U.S. Department of Agriculture's Forest Products Laboratory, Madison, Wisconsin; American National Standards Institute (ANSI), New York; the International Organization for Standardization (ISO), Geneva, Switzerland; and by several material-handling committees of the American Society of Mechanical Engineers, New York, which are working on unit-load and pallet standards.

There also are many testing techniques created and used by the manufacturing industries that produce packaging components from paper and paperboard; plastics, films, and sheet; steel and tinplate; aluminum sheet and foil; and wood. (See the chapters on these subjects for further information on design and quality-assurance procedures). This chapter will deal with preshipment testing of new packages to determine their resistance to the hazards of transportation and storage.

Fundamentals

Testing must be planned ahead of time to avoid unnecessary work, save time, and ensure satisfactory results. This means deciding what method is best for obtaining the desired information and what materials and equipment will be needed. The method selected ought to be consistent with standard practice in other organizations, it should be reproducible by other people at other times, and it should be free of personal bias. The work must be

TABLE 18.1. Selected Standards on Packaging.

From Selected ASTM Packaging Standards	
B-117-90	Test Method of Salt Spray (Fog) Testing
D-528-87 (1992)	Test Method for Machine Direction of Paper and Paperboard
D-585-93	Practice for Sampling and Accepting a Single Lot of Paper, Paperboard, Fibreboard, and Related Product
D-642-90	Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads
D-644-89	Test Method for Moisture Content of Paper and Paperboard by Oven Drying
D-685-93	Practice for Conditioning Paper and Paper Products for Testing
D-774-92	Test Method for Bursting Strength of Paper
D-828-93	Test Method for Tensile Breaking Strength of Paper and Paperboard
D-895-79 (1994)	Test Method for Water Vapor Permeability of Packages
D-951-88	Test Method for Water Resistance of Shipping Containers by Spray Method
D-996-92	Terminology of Packaging and Distribution Environments
D-998-86	Test Method for Penetration of Liquids into Submerged Loaded Shipping Containers
D-999-91	Test Methods for Vibration Testing of Shipping Containers
D-1029-84 (1990)	Test Method for Peeling Resistance of Paper and Paperboard
D-1083-91	Test Methods for Mechanical Handling of Unit Loads and Large Shipping Cases and Crates
D-1185-85 (1989)	Test Methods for Pallets and Related Structures Employed in Materials Handling and Shipping
D-1596-91	Test Method for Dynamic Shock Cushioning Characteristics of Packaging Material
D-1894-93	Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting
D-1922-93	Test Method for Propagation Tear Resistance of Plastic Film and Thin Sheeting by Pendulum Method
D-1974-92	Practice for Methods of Closing, Sealing, and Reinforcing of Fibreboard Shipping Containers
D-2176-89 (1993)	Test Method for Folding Endurance of Paper by the M.I.T. Tester
D-2221-68 (1984)	Test Method for Creep Properties of Package Cushioning Materials
D-2561-91	Test Method for Environmental Stress-Crack Resistance of Blow Molded Polyethylene Containers
D-2658-91	Test Method for Determining Interior Dimensions of Fibreboard Boxes (Box Gage Method)

(continued)

TABLE 18.1. (continued).

D-2860-90	Test Method for Adhesion of Pressure-Sensitive Tape at 90 Angle, D-2860M-90 Metric
D-3078-84	Test Method for Leaks in Heat-Sealed Flexible Packages
D-3079-72 (1984)	Test Method for Water Vapor Transmission of Flexible Heat-Sealed Packages for Dry Products
D-3103-92	Test Method for Thermal Insulation Quality of Packages
D-3199-84	Test Method for Water Vapor Transmission Through Screw-Cap Closure Liners
D-3330-90	Test Method for Peel Adhesion of Pressure-Sensitive Tape at 180 Angle, D-3330M-90 Metric
D-3332-92	Test Method for Thermal Insulation Quality of Packages
D-3473-88	Test Method for Lifting Force Required to Remove Certain Child-Resistant Snap Caps
D-3480-88	Test Methods for Downward Force Required to Open or Activate Child-Resistant Snap-Engagement Packages
D-3654-88 (1993)	Test Method for Holding Power of Pressure-Sensitive Tapes, D-3654M-88 Metric
D-3662-88 (1993)	Test Method for Bursting Strength of Pressure-Sensitive Tapes, D-3662M Metric
D-3759-88 (1993)	Test Method for Tensile Strength and Elongation of Pressure-Sensitive Tapes
D-3889-88 (1993)	Test Method for Adherence to Linerboard of Pressure-Sensitive Tape at Low Temperature, D-3889M-88 Metric
D-3950-90	Specification for Strapping, Nonmetallic (and Joining Methods)
D-3951-90	Practice for Commercial Packages
D-3953-91	Specification for Strapping, Flat Steel, and Seals
D-4003-92	Methods of Controlled Horizontal Impact Test for Shipping Containers
D-4168-88	Test Methods for Transmitted Shock Characteristics of Foam-in-Place Cushioning Materials
D-4169-93	Practice for Performance Testing of Shipping Containers and Systems
D-4279-83 (1988)	Test Method for Water Vapor Transmission of Shipping Containers—Constant and Cycle Methods
D-4332-89	Practice for Conditioning Containers, Packages, or Packaging Components for Testing
D-4521-91	Test Method for Coefficient of Static Friction of Corrugated and Solid Fibreboard
D-4577-86	Test Method for Compression Resistance of a Container under Constant Load
D-4675-93	Guide for Selection and Use of Flat Strapping Materials
D-4727-91	Specification for Corrugated and Solid Fibreboard Sheet Stock (Container Grade) and Cut Shapes, D-4727M-91 Metric

(table continued on next page)

TABLE 18.1. (continued).

D-4728-91	Test Method for Random Vibration Testing of Shipping Containers
D-4919-89	Specification for Testing of Hazardous Materials Packagings
D-4991-89	Test Method for Leakage Testing of Empty Containers by Vacuum Method
D-5077-90	Terminology Relating to Electrostatic Discharge (ESD) Packaging Materials
D-5094-90	Test Methods for Gross Leakage of Liquids from Containers with Threaded or Lug Style Closures
D-5112-90	Test Method for Vibrations (Horizontal Linear Sinusoidal Motion) Test of Products
D-5118	Practice for Fabrication of Fibreboard Shipping Boxes, D-5118M Metric
D-5168-91	Practice for Fabrication and Closure of Triple-wall Corrugated Fibreboard Containers
D-5264-92	Test Method for Abrasion Resistance of Printed Materials by the Sutherland Rub Tester
D-5265-92	Test Method for Bridge Impact Testing
D-5276-92	Test Method for Drop Test of Loaded Containers by Free-fall
D-5277-92	Test Method for Performing Programmed Horizontal Impacts Using an Inclined Impact Tester
D-5330-93	Specification for Pressure-Sensitive for Filament-Reinforced Packaging, D-5330M-93 Metric
D-5331-92	Test Method for Evaluation of Mechanical Handling of Unitized Loads Secured with Stretch Wrap Materials
D-5415-93	Test Method for Evaluating Load Containment Performance of Stretch Wrap Materials by Vibration Testing
D-5445-93	Practice for Pictorial Markings for Handling of Goods
D-5486-93	Specification for Pressure-Sensitive Tape for Packaging, Box Closure, and Sealing, D-5486M-93 Metric
D-5487-93	Test Method for Simulated Drop of Loaded Containers by Shock Machines
D-5488-93	Terminology of Environmental Labeling of Packaging Materials and Packages
E-96-90	Test Methods for Water Vapor Transmission of Materials
F-1140-88	Test Methods for Failure Resistance of Unrestrained and Nonrigid Packages for Medical Applications
G-26-90	Practice for Operating Light-Exposure Apparatus (Xenon Are Type) with and without Water for Exposure of Nonmetallic Materials

(continued)

TABLE 18.1. (continued).

G-53-93	Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials
Packaging Standards Located in Other ASTM Volumes	
A-623-92	Specification for Tin Mill Products, General Requirements (Volume 01.06), A-623M-92 Metric
A-624-90	Specification for Tin Mill Products, Electrolytic Tinplate, Single-Reduced (Volume 01.06), A-624M-90 Metric
C-149-86 (1991)	Method of Thermal Shock Test on Glass Containers (Volume 15.02)
D-646-92	Test Method for Grammage of Paper and Paperboard (Weight Per Unit Area) (Volume 15.09)
D-1251-79 (1987)	Test Method for Water Vapor Permeability of Packages by Cycle Method (Volume 15.09)
D-3066-91	Practice for Labeling Aerosol Packages (Volume 15.09)
D-3071-79 (1984)	Method of Drop Testing of Glass Aerosol Packages (Volume 15.09)
D-3611-89	Practice for Accelerated Aging of Pressure-Sensitive Tapes (Volume 15.09)
D-3652-93	Test Method for Thickness of Pressure-Sensitive and Gummed Tapes (Volume 15.09), D-3652M-93 Metric
D-3715-93	Practice for Quality Assurance of Pressure-Sensitive Tapes (Volume 15.09)
D-3811-88	Test Method for Unwind Force of Pressure-Sensitive Tapes (Volume 15.09), D-3811M-88 Metric
D-3813-88	Test Method for Curling and Twisting on Unwinding of Pressure-Sensitive Tapes (Volume 15.09), D-3813-88 Metric
D-3815-89	Practice for Accelerated Aging of Pressure-Sensitive Tapes by Carbon-Arc Exposure Apparatus (Volume 15.09), D-3815M-89 Metric
D-3816-88	Test Method for Water Penetration Rate of Pressure-Sensitive Tapes (Volume 15.09), D-3816M-88 Metric
D-3833-88	Test Method for Water Vapor Transmission of Pressure-Sensitive Tapes (Volume 15.09), D-3833M-88 Metric
D-4504-91	Specification for Molded Polyethylene Open-Head Pails for Industrial Shipping (Volume 15.09)
D-4649-87	Guide for Selection of Stretch, Shrink, and Net Wrap Materials (Volume 15.09)
D-4675-93	Guide for Selection and Use of Flat Strapping Materials (Volume 15.09)
D-5105-90	Practice for Performing Accelerated Outdoor Weathering of Pressure-Sensitive Tapes Using Concentrated Natural Sunlight (Volume 15.09)

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TABLE 18.1. (continued).

E-171-87	Specification for Standard Atmospheres for Conditioning and Testing Materials (Volume 15.09)
E-685-93	Practice for Testing Fixed-Wavelength Photometric Detectors Used in Liquid Chromatography (Volume 14.01)
F-88-85 (1994)	Test Method for Seal Strength of Flexible Barrier Materials (Volume 15.09)
F-372-73 (1984)	Test Method for Water Vapor Transmission of Flexible Barrier Materials Using an Infrared Detection Technique (Volume 15.09)
F-392-93	Test Method for Flex Durability of Flexible Barrier Materials (Volume 15.09)
F-1306-90	Test Method for Slow Rate Penetration Resistance of Flexible Barrier Films and Laminates (Volume 15.09)

(Note: Copies of the above standards may be obtained by contracting ASTM; Bar Harbor Drive; West Conshohocken, PA 19428-2959)

Packaging Test Methods Developed by TAPPI

T-208	Moisture in Wood, Pulp Paper, and Paperboard by Toluene Distillation
T-410	Grammage of Paper and Paperboard (Weight Per Unit Area)
T-411	Thickness (Caliper) of Paper, Paperboard, and Combined Board
T-414	Internal Tearing Resistance of Paper
T-423	Folding Endurance of Paper (Schopper Type Tester)
T-441	Water Absorptiveness of Sized (Non-Bibulous) Paper and Paperboard (Cobb Test)
T-803	Puncture Test of Containerboard
T-808	Flat Crush Test of Corrugated Board
T-810	Bursting Strength of Corrugated and Solid Fibreboard

Packaging Test Methods Developed by ISTA

Preshipment Test Procedure 1, 1A

For testing packaged products weighing less than (1A) or more than (1) 100 lb (45.4 kg) when prepared for domestic shipment

Preshipment Test Procedure 2, 2A

For testing packaged products weighing less than (2A) or more than (2) 100 lb (45.4 kg), which are to be exported outside the continental limits of the country of origin

Procedure 5, LTL Item 180

An alternative for *National Motor Freight Classification* Item 689 (Test Shipment Permit Program) and other packaging rules except those relating to drums, pails, bags, and numbered packages, it is recommended for solving chronic damage problems in LTL (less-than-truckload) shipments.

carefully and thoroughly done, and accurate records must be kept. Interpretation of the results is especially important, and this takes knowledge and skill that come only with considerable training and experience. It should be assumed that the methods and results will be challenged at some future time and, therefore, the packaging technologist should make sure that the work is defensible under any circumstances. This takes a little forethought and meticulous attention to details. Without advance planning, all the effort and expense for the tests may be completely wasted.

A distinction should be made at this point between "performance" and "properties" tests. It is always preferable to evaluate packages in their final form and under actual conditions of manufacturing, storage, transportation, and end use. This may not always be possible, but every effort should be made to approach these ideal conditions in testing the performance of a package and to follow up at a later date with a more realistic test, if necessary.

But sometimes answers are needed in the development stages, when materials and the actual environment are not accessible. Then it becomes necessary to do the work piecemeal and extrapolate the results in an attempt to predict the final performance of the package on the basis of the various properties involved.

Another basic decision to be made at the start of a test program is whether to seek average typical results or to determine the magnitude of the effects from the most extreme conditions the package could experience. The answer may depend on the value and availability of the product. Very costly one-of-a-kind turbine-generator sets, for example, simply cannot be damaged in shipment and, therefore, the packaging design and mode of transport must reflect the worst circumstances imaginable.

For more mundane consumer items, which are shipped in huge quantities, a packager may even accept a certain degree of damage as the balance between the cost of perfection and the competitive necessity to attain an acceptable market price for the product. However, there is a danger in this approach if the amount of product and packaging materials that are used for test purposes is small. Then, there is a statistical risk that a serious defect may not be discovered in the testing program. For example, a small number of containers for glassware may pass a test with no breakage and yet have a potential for 10 percent damage that would show up in a test of larger scale. In such cases, it might be wiser to simulate the worst hazards of shipment, but then set the level of acceptance at a lower point—that is, use a drop height of 24 in. instead of 18 in., but allow a breakage rate of, say, 2 percent to be acceptable in the test.

The ultimate objective is to relate the test results to actual conditions, but this ideal situation can never be fully realized. It is better to recognize that laboratory conditions can never simulate actual experience in every detail and make the necessary allowances.

Accelerated test conditions are useful for getting information ahead of long-term tests. Thus, higher temperatures will usually speed up chemical reactions, so that one month at 100 F (38 C) may correspond to a year's storage at room temperature, and three-quarters of an hour on a vibratory tester may be equivalent to a 1,000-mi (1,609-km) truck ride. It must be emphasized, however, that the results obtained under artificial conditions cannot safely be related directly to standard conditions, but can be taken only as an indication of what may occur in normal situations.

One way to approach reality in short-term tests is to relate results to a known standard, such as putting another similar package, which is performing satisfactorily in the field, through the same tests and using it as a control. In this situation, it may be desirable to run both tests "to destruction" to get a good comparison. However, reality will always remain an actual shipping test in which packaged product is subjected to actual handling, storage, and shipment conditions.

Despite excellent work in the development of test methods by the technical bodies mentioned earlier, there still seems to be no agreement among experts as to what constitutes a good test program and many laboratories continue to set their own procedures.

Rules and regulations for the packaging of hazardous materials are specified by several groups depending on mode of travel. Ground transport is governed by the U.S. Department of Transportation, Washington, D.C., and modeled after the United Nations' *Recommendations on the Transport of Dangerous Goods;* water transport by the International Maritime Organization, London, England; and air transport by two Montreal-based organizations, the International Air Transport Association and the International Civil Aviation Organization.

To reduce damage claims for nonhazardous commercial products in corrugated boxes and other containers that may be shipped by rail and truck, the National Railroad Freight Committee, Atlanta, and the National Motor Freight Traffic Association, Alexandria, Virginia, have set *minimum* standards in the *Uniform Freight Classification* and *National Motor Freight Classification,* respectively.

Federally purchased goods and military items have their own definitive specifications (see Chapter 20, Laws and Regulations).

However, the evolution of all really effective test standards had to await the development of testing equipment that could simulate shipping and storage conditions with reproducible data. As mentioned before, there now are countless tests and testing machines for every aspect of container and packaging analysis. This handbook is not the place to enumerate them all, but an overview will provide a glimpse of what is available.

There are five basic machines that can simulate just about every shipping condition and pretest product containers and shippers to avoid costly damages. There is also a distribution test procedure engineers can use to plot all kinds of shipping conditions and the test conditions that simulate them. First, the equipment.

Testing Equipment

An early, rather primitive test method was to actually tumble a package down a flight of stairs or even drop it from the story-high roof of the manufacturing plant. It is certainly possible to find weakness in a shipping unit this way, but, needless to say, it is not very repeatable. This led, however, to development of today's testing machines.

“Drop testers” simulate vertical shocks to packaged goods caused by dropping during loading and unloading activities. The test can be done by hand, but the instruments facilitate accurate height and positioning for dropping a loaded shipper onto a rigid and immovable surface of concrete, stone, or steel plate [at least 0.5 in. (1.3 cm) in thickness] on its flat surfaces, edges, and corners. The loaded shipping container is held in place on two horizontal latched leaves that, when released, pivot apart to drop the container (see Figure 18.1). This device can accommodate rectilinear, round, and bag shapes up to 110 lb (50 kg). There is also a block-and-tackle hoist-and-sling

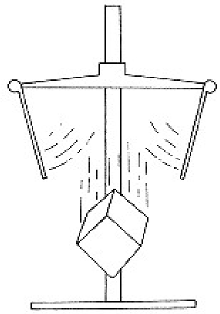

Figure 18.1.
In a drop tester, the package is positioned flat or at an angle on the drop table, which is set at the desired height. A latch release allows the table to swing out of the way, under spring pressure, permitting the package to fall freely onto a hard surface.

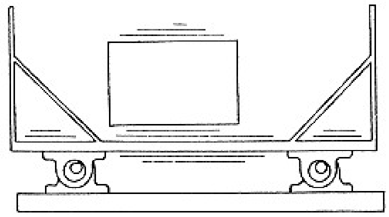

Figure 18.2.
In a vibratory tester, the package is placed unsecured on a shaker table, and frequency of vibration is increased until the package starts to leave the table. The test is continued at this frequency for the required time.

device with a cable trip for raising and dropping heavier containers such as filled drums.

A "vibration tester" simulates the range of vibratory motions imparted to packaged goods in truck and rail transit. The device consists of a strongly built rigid table, which remains level under conditions of use and transmits the applied and variable vibrations uniformly over the entire table surface (see Figure 18.2). The machine should be capable of fastening test products firmly to the table surface or permitting packaged goods to vibrate freely. Machines can be built to provide linear, rotary, or sinusoidal vibratory motions. Most usual is a vertical linear motion. The unit should be equipped with fences and barriers to keep test packages on the table and permit testing of multiple packages arranged horizontally or stacked vertically to a reasonable height to determine effects on containers located at different levels in a load. Controls should enable vibrations to range over wide frequencies and amplitudes, but most testing is done at 1 G+ for an hour, which is generally considered to be equivalent to a 1,000-mi (1,609-km) trip. Instrumentation is available to automatically or manually reproduce calculated test conditions or to operate on recorded data from actual transport shipments.

A "shock machine" is most useful in determining the fragility of a product and/or its components and the required level of protection. Use of this machine also can result in the replacement or relocation of product components to eliminate or reduce their fragility and, therefore, the damage sensitivity of the entire product.

The machine consists of a horizontally surfaced carriage that is strong and rigid enough to resist drop forces and is fitted with restraints to hold products under test. In action, the table free-falls and strikes a shock pulse programmer (a bumper) and is then arrested on the rebound to provide only a single shock. Instruments measure shock-table impact and rebound velocity and calculate the critical velocity of the test sample. The end result is a damage boundary curve that delineates in a horizontal line the peak acceleration of the minimum damaging shock pulse and in a vertical line the minimum velocity change (drop height) that causes damage.

An "incline-impact tester" produces a horizontal impact designed to duplicate the effects of railroad humping (forceful coupling of cars at speed), swaying motions of ship cargos, or very abrupt stops by trucks containing loose loads, and other similar horizontal impacts, particularly on less than full loads. The instrument consists of a wheeled carriage mounted on rails that are adjustable in angle and in the starting point of the carriage. The carriage is retained in position by a latching mechanism. The carriage and its load of a single package, several packages, or even a pallet load are positioned at the desired track location and angle, usually 10 , to create the desired shock. The carriage is then released to ram into a massive bulkhead located at the foot of the rails and positioned at right angles to the carriage bed (see Figure 18.3). This bulkhead also can be equipped with padding of different resiliencies to create more or less shock, but this also leads to variations between tests run at different laboratories. Results from incline tests are similar to the drop test and the data often can be equated.

To this point, testing has involved containers in movement. But a distribution package also spends a great deal of its time in warehouses exposed to the surrounding environment and the weight of other distribution packages and their pallets in stacks that, today, sometimes can tower 20 ft (6.1 m) high. Many shipping packages, corrugated boxes in particular, are drastically weakened by exposure to high levels of humidity. But even a dry box held at standard manufacturing and storage conditions of 70 F (21 C) and 50 percent RH can succumb to high stacking unless the product containers inside provide total support. Since many containers offer little or no support, it is

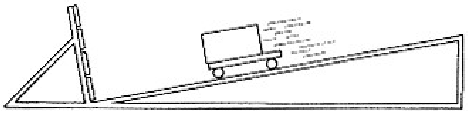

Figure 18.3.
In an incline-impact tester, one or more packages are placed side by side or stacked on a dolly and rolled up a 10 incline for the required distance and latched into place. Upon release, the dolly travels freely down the track until it hits a solid wall.

vital for the packaging engineer to know in advance what kind of warehouse storage load his shipper is supposed to support and for how long.

The machine designed for this purpose is the "compression tester." This instrument contains two platens, the bottom one stationary and the top one connected to a mechanical, pneumatic, or hydraulic piston, which can be programmed to compress a shipping package between the two plates at a constant pressure or to steadily increase compression to destruction of the package. The tester has a timer to measure the time taken to cause container failure and an indicator to measure the box deformation while under load. Today, such data generally are recorded automatically. Containers can be tested either empty or filled and sealed. Although generally tested on the flat surfaces containers such as crating also can be tested on diagonal edges. Equipment ranges from a small tester that holds only one shipper to large-platen units that can hold an entire pallet tier.

The "revolving drum" is little used today, but might return with the growth of fast-delivery carriers, which sort for destination by tumbling packages down over staggered conveyors, toss them into trucks during loading, and frequently unload by dropping them onto pavements from truck tailgates.

The device is a giant, slowly turning wheel, which carries a package part way up the inside surface and then allows it to tumble back to the bottom, striking various bars and points that are fastened to the inside of the drum, or in some designs being bounced over an interior shaped like a hexagon (see Figure 18.4). Its invention corroborates the widely held viewpoint among packaging engineers that although the United States may have the most complete distribution system in the world, it is also one of the roughest. While there seems to be a place for the revolving drum, it does take up a lot of room and, in fact, most of its actions can be simulated with the drop tester, the vibrator, and/or the incline-impact tester.

Commercial and university laboratories and some packagers and suppliers have very sophisticated equipment, today, which can perform drop tests onto surfaces with different hardnesses and resiliencies. Vibration tests can be cycled through a "sweep" of frequencies from 3 to 100 Hz. This can be important if there is a natural or resonant frequency in the package itself or its contents that could be amplified by a similar frequency in shipping vibration. A sweep will disclose the duplicated frequency.

Relatively new are giant compression, drop, and horizontal-impact testers, which can handle whole pallet loads and create the same simulations used to test single packages.

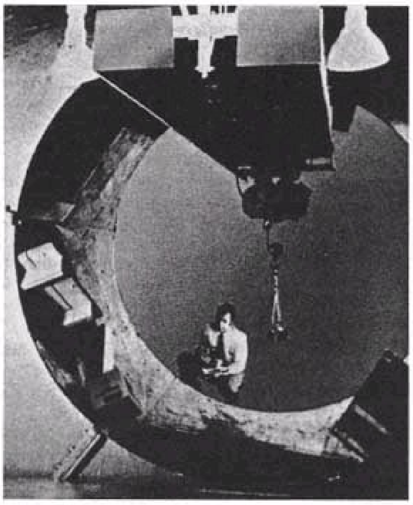

Figure 18.4.
Although not used that much today, the revolving drum, a giant, slowly revolving wheel with hazards fastened inside could be useful in duplicating the LTL environment. As the drum rotates, package(s) inside are carried partway up the side and then tumble down to the bottom striking the hazards. This is continued for the required number of falls.

Distribution Testing

It is important to carefully plan tests for distribution packaging. Fortunately, some five generations of packaging engineers have developed a host of organized tests for distribution packaging.

The first important test and one that continues to be widely used today, particularly for acceptance by the rapid-delivery services, was developed in 1945 and kept current by ISTA and its predecessor organizations. This preshipment test is divided into two parts: Project 1 for packages weighing more than 100 lb and Project 1A for packages weighing up to 100 lb. Project 2 and 2A are for export packaging and have added climate conditioning and intensified compression, vibration, and impact tests. Similar and fast to perform, if done correctly, both are very good predictors of package performance in a tough distribution environment.

Unquestionably the most brilliant breakthrough in preshipment distribution testing was created in 1982 by ASTM, which developed and continues to update the *Standard Practice for Performance Testing of Shipping Containers and Systems,* the current protocol being published in 1994.

Until recently, less-than-truckload (LTL) shipments have been treated the same as full-truckload shipments, despite the fact that the LTL environment is usually rougher. Standard shipments are subject to Rule 222, which specifies maximum sizes and weights of packaged products and the minimum fibreboard strength specifications determined by burst or edgewise crush tests. Now, a new Rule 180 of the *National Motor Freight Classification* has been developed in cooperation with the Institute of Packaging Professionals (IoPP), Herndon, Virginia, for LTL shipments that can range from single products or packages to single pallet or skid loads. Currently undergoing a three-year test period, the rule's performance will be reexamined in January 1998.

We will discuss these three tests, since their procedures underlie almost every other distribution test ever created.

ISTA Project 1 A [1]

This preshipment test consists of vibratory and drop tests with an alternative incline or horizontal impact test for the drop test and an extra compression test, where storage is an important distribution component. The tests must be run in sequence and success is certified by ISTA. Any change in either the product or the package requires retesting for recertification.

The vibration test, performed first in accordance with ASTM D-999, Method A1 or A2, can employ rotary, vertical-linear, or linear motion, as desired. The frequency of motion is the minimum speed at which a 1/16 in. (1.6 mm) shim can slide at least 4 in. (10.2 cm) under the shipper as it leaves the vibratory table. Test duration is 14,200 vibratory impacts divided by the cycles per minute frequency. The package should be rotated 90 degrees at the halfway point (no rotation is necessary for vertical-linear motion). The package is then examined for visible damage and product looseness. Where possible, the package should be opened for inspection and then reclosed.

The drop test is performed with equipment complying with ASTM D-775 and TAPPI T-802; ASTM D-3332, Method B; ASTM D-880, ASTM D-4003, or TAPPI T-801 and can control the package with either a split-leaf mechanism or a suitable sling-and-trip device for heavier or awkwardly shaped products.

To perform the test, the panels, edges, and corners must be identified by numbers with the manufacturer's joint corner end facing the test person with the joint on the right side. In this orientation, the case top is (1), right side (2), bottom (3), left side (4), near end (5), and far end (6). Edges are identified by the panels that form the edge. The edge formed by the top and right side, for example, is edge 1–2. A corner is identified by the three surfaces that form it. For example, corner 2–3–5 is created by the right side, bottom, and near end.

Drop heights, determined by package weight, are divided into four groups from 1 to 100 lb (0.45 to 45.36 kg). Drop heights range from 30 in. (76.2 cm) for the lightest group to 12 in. (30.48 cm) for the heaviest. Ten drops must be done in order, starting with a corner drop, three edge drops, and a single drop on each of the six faces. After this admittedly severe test, the package has survived if the product is undamaged and the shipper still affords reasonable protection to the contents.

If the package shape is not conducive to dropping, then the incline/horizontal impact test can be substituted. The same package numbers, weight classifications, and corner, edge, and flat-surface impacts are employed. Four different impact velocities, however, are substituted for the drop heights.

Where interim storage during distribution is a shipping factor, a compression test is added to the procedure. Test equipment complying with ASTM D-642 or TAPPI T-804 is required. The package is centered on the test platen with a pallet either above or below the case where that is applicable in shipment. The top and bottom platens are then brought together at the rate of 0.5 in. (1.27 cm) per minute for 1 hr. The package and product survive the test if the product is free from damage and the shipper still affords sufficient product protection and has enough rigidity to be safely restacked.

This test frequently has been criticized as too severe, particularly because of the 2–3–5 corner drop. Admittedly, there are some products incapable of surviving this test, fragile glassware, for example. However, for most products and for packagers who desire zero breakage, this test is ideal.

Standard Practice for Performance Testing [2]

"This procedure provides a uniform laboratory method for evaluating the ability of shipping units to withstand the distribution environment by subjecting them to a test plan that consists of a sequence of anticipated hazards encountered in various distribution cycles," states the beginning of ASTM D-4169. The procedure also complies with the packaging design provisions of MIL-STD-2073-1 and is, therefore, acceptable for government packaging systems.

The various testing levels in this procedure are based on real data from the shipping and handling environment and on the current practices and experience of industry and government packaging engineers.

Filled and sealed distribution packages are first categorized as to the precise shipping unit, which could range from a single shipper up to a pallet load. This unit is then rated for its Acceptance Criteria, which normally means that after the test, the packaged products are acceptable for sale. The packaged goods are then conditioned. Normally, the containers will be tested at a standard atmosphere of 73.4 F ±2 (23 C ±1) and 50 percent RH ±2 percent.

A testing Assurance Level is then determined. There are three preestablished levels. Assurance Level I is more severe than Level II, which is more severe than Level III. Selection of the desired level is based on product value, the acceptable level of product damage, the number of units to be shipped, and the engineer's knowledge of the shipping environment. A final Test Acceptance Criteria is either (1) damage-free product or (2) intact packages. One is chosen based on requirements.

The Testing Cycle is then determined from a table containing eighteen different schedules, each of which can have as many as six tests, starting with a climate hazard; then, handling by manual or mechanical methods; stacking in vehicles, railcars or warehouses; vibration in stacks, loose loads, vehicles, or railcars; a second vibratory function that can include manual handling, warehouse stacking, loose-load vibration, or rail switching; and a final possible distribution step or warehouse stacking or manual handling. The elements in each of these tests are defined and discussed in a series of tables of assembled data, formulas, instructions, and referenced ASTM test procedures. The sequences and choices are somewhat complex and it is strongly suggested that the packaging engineer make a list of the desired procedures.

The tests are then performed according to the test plan, and the products and packages are examined to determine if the Acceptance Criteria have been met. It is a long way from that old staircase or plant roof and the safe distribution of goods is all the better for it.

Rule 180-A for LTL Shipments [3]

Two optional methods are provided in the new LTL shipment test. The difference is that in Method A vibration and compression are conducted simultaneously by using a concentrated deadload on top of the package(s). The deadload is calculated from a formula involving the density of the load, its height, length, and weight and the height of the truck trailer. For packages weighing less than 30 lb (14 kg) or measuring less than 2 ft^3 (0.056 m^3), the formula is somewhat decreased.

The deadload is composed of RSC (regular slotted case) double-wall corrugated shippers containing a plywood stiffening sheet and sand in plastic bags. It must extend just beyond the edge of the test shipment and be fixtured so it cannot move laterally. The test shipment is free to move laterally, but fixtured so it cannot move out from under the deadload.

In Method B, the formula substitutes pounds of force for density and adds a Design Factor as a multiplicand ranging from 3.0 for load-supporting products or wooden boxes to 4.5 for corrugated products with interior wooden supports to 7.0 for corrugated containers with or without interior corrugated cushioning and where the load does not support the container. Since a top load is not specified, this test would be run on a compression machine. Again, for the smaller and lighter containers, the test parameters are reduced.

The concluding impact test has three procedures. For packages weighing less than 200 lb (91 kg), the free-fall drops (Procedure A) are scaled from 10 to 24 in. (25.4 cm to 61 cm) depending on weight for six drops (on the top, two adjacent bottom edges and two diagonally opposite bottom corners). The final drop must be 1.5 times the specified drop height. In fact, the package should be designed to withstand drops from the specified height in any orientation. Packages weighing more than 200 lb (91 kg) can elect a drop or a rotational drop test from 6 in. (15.2 cm) on the top, two adjacent sides, and bottom. As an alternative, for packages weighing more than 200 lb (91 kg), an incline, horizontal, or pendulum impact test can be performed by impacting the top, two adjacent sides, and bottom package panels at a final dolly velocity of not less than 5.75 ft/sec (1.75 m/sec).

For packages with attached pallets or skids including crates, Procedure B, a raised drop test of 12 in. (30.5 cm) is allowed for containers weighing less than 500 lb (227 kg), while a 9-in. drop (22.9 cm) is specified for containers weighing more than 500 lb (227 kg).

Procedure C is for palletized or otherwise unitized loads of multiple containers, which are impacted according to the two tests in Procedure B and then subjected to a fork-truck handling test in which the load is picked up on 36-in. (91 cm) forks and driven around a course specified in ASTM D-1083 containing a right-angle turn and a bounce over two 2   4 ft (5.1   10.2 cm) boards at a speed of at least 2 mph (0.9 m/sec). Vertical alignment of containers must be reasonably maintained throughout the test.

References

1. National Safe Transit Association. April 1990. "Project 1-A," *Pre-shipment Test Procedures*.

2. ASTM (American Society for Testing and Materials). 1994. "ASTM D-4169," *Standard Practice for Performance Testing of Shipping Containers and Systems*.

3. National Motor Freight Traffic Association. 1995. "Rule 180-A for LTL Shipments," *National Motor Freight Classification.*

Chapter 19— Quality Control

Introduction

In the process of designing a new package, seeing it through the various stages of development, and ultimately following it to its final destination, the packaging engineer will undoubtedly have to deal at some point with the problems of quality control. In this section we will discuss a few of the basic principles in order to acquaint the reader with the terminology and techniques that are used for this work.

It is not possible to cover such a broad subject fully in these few pages, but a brief treatment may help to familiarize the reader with the basic aspects of inspection and control. For more comprehensive coverage, we suggest *Maynard's Industrial Engineering Handbook,* Fourth Edition by Harold Bright Maynard and William K. Hodson, published in 1992 by McGraw-Hill, New York. Two other possibilities are *Statistical Quality Control,* Seventh Edition by Eugene L. Grant and Richard S. Leavenworth (McGraw-Hill, 1996) and *Introduction to Statistical Quality Control,* Third Edition by Douglas C. Montgomery (John Wiley and Sons, New York, 1996).

Modern methods of quality control (QC) of packaging as well as products came into sharp focus after World War II, when producers shifted from the war-time pressure to get things out, no matter what, to a civilian market that was totally fed up with the war-time shortages and relatively poor quality.

Many companies that didn't get the message fast enough, particularly in the food field, went out of business. QC became of paramount importance and in many firms, new managerial employees had to spend a term in quality inspection before they were permitted to practice the job for which they had been hired.

Forty years later, the cycle was completed and the maintenance of high quality products, their packaging, and the excellence of the machines that produce and apply the packages was once again called into question. It started in Europe, not only with growing disapproval by users of the quality levels in products from some of their suppliers, but also because of the widely different standards for quality and methodology in existence from country to country on the Continent.

To the rescue came the International Organization for Standardization (ISO), Geneva, Switzerland, a group of 91 national standards bodies that includes the American National Standards Institute, New York, which set up Technical Committee 176 with the mission to "harmonize" (make uniform) the many independent standards in individual countries.

The ISO standards and guidelines that were quickly developed do not mandate specific methods, but rather require a company to document that it has a quality-control system and that it operates according to that system. Registration with ISO is done on a plant-by-plant basis with an audit by a third-party inspector with additional semiannual visits and triennial reassessments. The Quality Management and Assurance protocols are contained in 15 documents numbered from ISO 9000 to 10013, which explain what guideline to use, and how to install a quality management system for product processing, inspection, and testing.

The system has caught on quickly in the United States with at least a minority of product suppliers, not only because uniformity in quality control is needed here, but also because many domestic companies do business in Europe, where purchasers are steadily moving toward requiring all of their suppliers to be ISO certified. The system is time consuming to establish, requires effort to administer, and is somewhat expensive to maintain and prove in subsequent inspections. However, executives of many U.S. companies, which have embraced the standards, have been outspoken in their approval of the resulting quality and personnel morale improvements.

Quality Control

Throughout the whole process of quality control there is an underlying discipline that is based upon the mathematical principles of probability. The true value of quality control is inherent in the ability to apply small bits of information to a large system, to show trends, and to predict consequences from a limited amount of information, to determine the condition of large quantities of material from small samples, and to know with a precise degree of certainty just how much of this information can be trusted. To understand the methods that are used to obtain this knowledge, we will look at some of the techniques used in statistics.

Frequency Distribution

If a group of pieces are accurately measured, small differences will be found among them. In spite of our best efforts to make pieces exactly alike, some small variations will always exist and cannot be eliminated. When the differences have been reduced to the very smallest variation possible, it is called the "inherent variability." In order to know whether this minimum has been reached, the frequency of the variations can be plotted as a distribution curve. A normal, bell-shaped curve has only one peak and is symmetrical about the center. That is, the greatest number of measurements should fall in the center, and fewer and fewer variations in measurement should be found as the distance from the center increases (see Figure 19.1).

A useful way to express such a distribution pattern is by means of a "standard deviation," which is the square root of the mean of the squares of the individual deviations, generally expressed by the Greek letter sigma, . The standard deviation measures the expected spread of measured values, as shown in Figure 19.2 and is used to set the limits for control.

If the standard deviation is applied to a process and more than a small percentage of products are found to be outside these limits, it can be assumed that something is happening beyond the inherent variability previously mentioned and that it can be controlled. The "three-sigma" limits, which can be

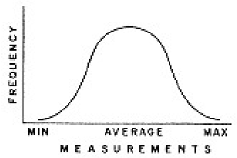

Figure 19.1.
In a frequency curve, any value such aslength, weight, or other measurement most frequently will be found close to the desired figure. The number of pieces that are above or below this value will be fewer and fewer as the deviation becomes larger. When these numbers are plotted on a graph, we get a histogram that follows the general shape shown here.

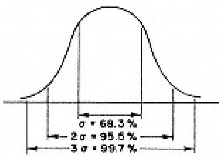

Figure 19.2.
The root-mean-square standard deviation of a set of measurements provides the expected distribution of those measurements, represented by , with the bulk located in the first sigma and fewer in the outer two sigmas of distribution. Measurements outside the three-sigma limits indicate an "unnatural" condition that is capable of being controlled.

expected to include 99.73 percent of all measurements, are called the "natural tolerance."

Properties that can be measured accurately are called "variables." These include such things as dimension, strength, chemical properties, or electrical characteristics. Sometimes there are qualities that cannot be measured, but simply are judged as good or bad, acceptable or defective, go or no-go. These are called "attributes."

Measuring quality on a continuous scale by variables gives a better indication of the true quality of an item. It tells you whether the quality is at the midpoint or on the low or high sides and just barely passable. To get the same degree of control on a go/no-go basis would require at least ten times as many pieces. Although it is possible to plot a curve for attributes similar to the one for variables by means of a binomial distribution technique or the Poisson distribution method, it is generally considered more practical to control by variables, where it is necessary to watch trends.

Process Control

If we turn the distribution curve on its side and project the lines from the center and from the three-sigma points, we have a control chart (see Figure 19.3). The value of a control chart is that it monitors a manufacturing process to ensure that the quality of the package and product is maintained at a constant level. By plotting the measurements of each sample as points on a chart, moving from left to right with time, we can see not only whether the item is within limits, but also whether there is a trend in one direction or another. Such a trend might indicate potential trouble, an investigation should be made to see whether the trouble can be headed off before it becomes serious.

Assignable Cause

If any points are beyond the three-sigma limit, we can say with 99.73 percent certainty that the cause of the variation is something other than normal. This is called an "assignable cause." Also, it is a general rule that if seven consecutive points of any data are all on one side of the midpoint, an assignable cause is at work.

Significance of Results

In any type of testing it may be necessary to determine whether enough tests were made to support conclusions. This can be calculated by a form of mathematics that is used mostly by statisticians. If the variations between individual results are so large as to throw doubt on the final average, the "t test" can be applied to see whether the variations could be considered normal.

A set of measurements can be called significant if it has a low probability of occurring by chance or, to put it another way, if it has a high probability of being caused by some outside force. The probability of a coin falling heads is 1/2 and of a die rolling one particular number is 1/6. The total of all the probabilities is always 1. That is, the probability of a die rolling any of the six numbers is the sum of the probabilities of rolling each particular number. If we wish to test a set of production-packaging figures for significance, we can use the t test in which t is the ratio of a variable quantity to the standard deviation of that quantity. The formula is:

$$t = \frac{\overline{X}}{S\,(\overline{X})}$$

where S $\overline{X}$ is the arithmetic average of a set of data. The *X* with a bar over it is called an "*X* bar," and is the simple sum of all the measurements divided by the number of measurements.

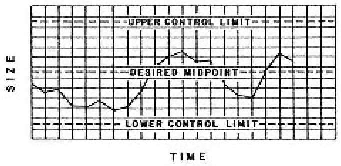

Figure 19.3.
Process control chart plots variations of a critical container dimension on a continuing basis to detect any trend, which indicates a problem in the making.

The average $\overline{X}$ is easily calculated, but the standard deviation is a little more complex:

$$S(\overline{X}) = \sqrt{\frac{n\Sigma X^2 - (\Sigma X)^2}{n^2(n-1)}}$$

where denotes the "sum of" and *n* is the number of measurements.

Three measurements must be reduced to the simplest form, so that the differences show up as simple digits. For example, where the mean is 2.500, the low measurement is 2.498, and the high measurement is 2.501, the applicable figures are -0.002, 0.000, and +0.001, which can be still further simplified to -2, 0, and +1. Add these together and we have:

$$\Sigma X = -2 + 0 + 1 = -1$$
$$n = 3$$
$$\overline{X} = 1/3$$
$$\Sigma X^2 = 4 + 0 + 1 = 5$$

Inserting figures into the formula, we have:

$$S(\overline{X}) = \sqrt{\frac{3 \times 5 - 1}{9 \times 2}} = \frac{3.74}{4.24} = 0.882$$
$$t = \frac{\overline{X}}{S(\overline{X})} = \frac{0.33}{0.882} = -0.377$$

Using the above equation the standard deviation is then 0.882 and the t is -0.377. Referring to the abbreviated Table 19.1 with these data, the "degrees of freedom" are found in the left-hand column, which is equal to *n* - 1, in this case, 2.

In our example, *t* is 0.377. Reading across the chart we find that this number lies between 0.70 and 0.80, or about 0.75. Therefore, a *t* value of 0.377 could occur from chance causes nearly 75 percent of the time and so it is not very significant. We need a value of less than 10 percent before we can read any meaning into our figures. Evidence of a difference when none really exists is called a "Type I" error. If the evidence indicates that there is no difference when one actually does exist, it is known as a "Type II" error.

Incoming Material

Quality control is a system of specifications, inspections, analysis, and recommendations. In the first phase it involves the establishment of criteria for judging the attributes of a product or a package, such as function, appear-

TABLE 19.1. t *Test of Significance.**

,	Degree of Confidence†											
Degrees of Freedom	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01
,1	0.158	0.325	0.510	0.727	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657
2	0.142	0.289	0.445	0.617	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925
5	0.132	0.267	0.408	0.559	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032
10	0.129	0.260	0.397	0.542	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169
20	0.127	0.257	0.391	0.533	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845
40	0.127	0.255	0.388	0.529	0.681	0.851	1.048	1.303	1.684	2.021	2.423	2.704
120	0.126	0.254	0.386	0.526	0.677	0.845	1.040	1.298	1.658	1.980	2.358	2.617

Lack of significance indicates that more must be done to find causes or to increase the degree of confidence. More complete tables for the value of t will be found in textbooks on statistics.

Degrees of freedom is one less than the number of measurements (n - 1)

†Results should fall in the far left column to be of any value.

ance, safety, or economy, which make it suitable for a particular purpose. The specifications set up for this purpose are based on knowledge and experience, plus some judgment as to the relative importance of each attribute.

It is a serious mistake to set rigid limitations when it is not necessary, just as it is wrong to provide more latitude than the situation warrants. Tight restrictions, where not pertinent, will not only needlessly increase costs and reduce productive output, but also can shift the emphasis away from some of the more critical points, which may result in a general lowering of overall quality. The fewer the number of different things that need to be measured, the greater the attention that can be given to each of them individually. When more information becomes available from additional experience, as much effort should be directed toward relieving specifications that may be too tight as toward holding the close tolerances while adding new specifications.

Basically, purchased material is inspected to determine whether it is acceptable. The criteria for measuring it are the ranges set in the specifications. However, it is not enough to establish the limits within which the measurements must fall. One also must predetermine what action should be taken if the inspector finds some samples that are outside the specifications.

Acceptance Levels

Whether attributes or variables are being checked, there are sure to be cases in which an occasional piece is outside the limits. The inspector will need to know at what point to consider the lot unacceptable. For this he requires an acceptance quality level (AQL), which is a percentage figure for the allowable number of defects. This will vary for different types of defects, depending upon their seriousness. In glassware, for example, the types of defects are classified as "critical," "major," and "minor" (see Chapter 9, Glassware). In such a case we might choose 0.25 percent for critical defects, 1.5 percent for major defects, and 4 percent for minor defects. However, for such highly regulated and functionally important products as medical or hazardous materials, a zero tolerance might be required for critical and even major defects in packaging.

Specifications

The heart of a quality-control system is the specification. This is what determines the degree of precision that must be used in the manufacturing department. Since it affects costs, production rates, sales volume, and many other aspects of the business, a great deal of thought should be given to this important document.

The specification is a communication from the designer to the purchasing department, and ultimately to the supplier. It also tells the inspector what to look for, which methods to use to check critical points, and how to deal with variations that may show up in the final product. The packager's inspectors should be able to practice quality assurance (QA), a check to make sure that the vendor has performed an adequate quality control (QC) of his packaging materials or containers.

To perform the latter job properly, the supplier should always possess an up-to-date copy of the specification, so that a thorough inspection can be made before parts are shipped. In many cases, today, where packagers form partnerships with their vendors, certification of quality by the vendor is actually accepted at face value, with little or no further inspection by the purchaser. This has the obvious advantage of reducing the in-plant cost of inspection for the packager, but it can be done with confidence only if the supplier is known to be reputable and has a history of producing consistently good material.

Standard Samples

The packaging technologist should furnish a sample of all new items to the inspection department. It may be a handmade sample or a first-piece sample from production tools, which can be used for temporary standards. In subsequent runs the inspector will replace these with up-to-date samples, which can be used for reference. It is not possible to cover every contingency in the written specification, but a standard sample often will help answer any questions, which may arise.

The packaging technologist should assume that the inspector has never seen the item before and therefore cannot be expected to know its function or how it relates to other components. The technologist also should realize that an inspector does not have the background information to determine the relative importance of the various characteristics of a part, and it is up to the designer to educate the inspector so that he can do an intelligent job of examining the items for defects.

Sampling

To determine whether a shipment of material is acceptable, it is necessary to know what percentage of defects would be found in the entire shipment. This can be calculated very accurately by examining a small amount and extrapolating the results, provided the methods that are used follow certain basic principles.

The manner in which samples are taken is an important part of this process. Any shipping cases that show obvious shipping damage should be excluded from sampling. Except for those, all items in a shipment must have an equal chance of being selected for testing. This is important, and the validity of an inspection report is dependent upon the manner in which the samples are chosen. Any method which provides a truly random sampling is satisfactory.

A "lot" for inspection purposes should be considered to be the quantity delivered by one vehicle, which is usually recorded on a single lot ticket. The number of cases of small items to be opened for sampling should equal the square root of the total number of cases plus 1. If the lot contains 10 cases or fewer, all should be opened and sampled. If the container is made in several dies or mold cavities, all should be represented in nearly equal quantities in the sample. If it is found that this is not the case, then additional samples should be taken until there is an adequate number for each position in the container tooling.

Size of Sample

How large a sample should be taken will depend upon the need for accuracy and reliability. One of the simplest methods for determining sample size is to take the square root of the total quantity in the lot. This tends to give sample quantities that are too small for small shipments and too large in the case of large lots. At least 100 samples are needed to get statistical results that are meaningful. Even then, a lot with 2.5 percent defective pieces will check out as though it were all perfect 4 percent of the time; that is, only 96 percent of the time will at least one defective piece appear in the sample group. Using 200 or more samples will greatly increase chances of picking up the all-important critical defects.

Many companies have long adopted the government standards for sample size, which are specified in MIL-STD-105D, a standard for sampling that is generally recognized throughout the world. It is available from the Superintendent of Documents; Washington, D.C. 20402; or from U.S. Naval Publications, Customer Service; 5801 Tabor Ave.; Philadelphia, Pennsylvania 19120. This document presents several levels of sample selection, the use of which depend upon the user's confidence in the quality level of the lot to be tested. A simplified version of one plan in this specification is given in Table 19.2.

Conventionally, a 95 percent probability of acceptance (5 percent probability of rejection) is considered the "producer's risk," while a 10 percent probability of rejection is usually taken as the standard "consumer's risk."

TABLE 19.2. Single Sampling Plan for Normal Inspection.

		Acceptable Quality Level‡								
Lot Size	Sample Size†	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5
2+	2	0	0	0	0	0	0	0	0	0
8	3	0	0	0	0	0	0	0	0	0
15	5	0	0	0	0	0	0	0	0	1
25	8	0	0	0	0	0	0	0	1	1
50	13	0	0	0	0	0	0	1	1	2
90	20	0	0	0	0	0	1	1	2	3
150	32	0	0	0	0	1	1	2	3	5
280	50	0	0	0	1	1	2	3	5	7
500	80	0	0	1	1	2	3	5	7	10
1,200	125	0	1	1	2	3	5	7	10	14
3,200	200	1	1	2	3	5	7	10	14	21
10,000	315	1	2	3	5	7	10	14	21	21
35,000	500	2	3	5	7	10	14	21	21	21
150,000	800	3	5	7	10	14	21	21	21	21
500,000	1,250	5	7	10	14	21	21	21	21	21

Inspection by attributes (go/no-go) at level II (normal) for acceptance or rejection on the basis of a single sampling

Number of units in a batch or shipment

†Number of units to be inspected that are selected at random from each lot

‡Acceptable if the number of defective units in the sample are this amount or less, rejectable if above

Inspection

Each item in the sample should be examined visually for any obvious defects. One or more should be handled in a way that simulates its end use. For example, a part should be fitted into its mating part, a cap should be tried on a bottle, and a box should be filled with its contents. Some defects will not show up when measured by gauges, but become apparent only when the parts are put to their intended purpose. Too often the inspector will overlook such faults because he is intent on following the letter of the specification, and he neglects to verify that the piece is functional.

Instruments

The methods and tools to be used will depend on the item being inspected. A few of the more common tests are listed in Chapter 18, Preshipment Testing. For repetitive tests, an investment in limit gauges will be repaid many times over. There is also a great deal less fatigue in working with a good set of tools than there is in reading the fine graduations of an all-purpose tool for long periods of time. A "rule of 10" states that an instrument should have divisions that are 10 percent of the unit of measure given in the specification. Thus, if the specified limits are given in thousandths of an inch, the finest division on the measuring instrument should be one ten-thousandth.

Paperwork

Accurate records of quantities, dates, lot numbers, and other pertinent information should be kept on all types of products and their packages and are mandated by law for some.

For complex packages and chancy sources of supply, a lot number should be assigned to all samples from a shipment and some samples should be filed under this number for future reference. The number of defects should be recorded so that trends can be noted and different sources can be compared. When defects are tabulated for determining acceptance or rejection, if there is more than one defect in a single piece, only the most serious defect should be counted and the others should be ignored. However, all defects should be entered in the records for analytical purposes.

Recommendations

It is not enough to inspect and analyze. There must also be a recommendation for action. Either the pieces are accepted and used or rejected and returned. In certain cases, intermediate courses are taken.

If the defects are only moderate in severity, the pieces can be accepted with a warning that corrective steps must be taken in the future. A more usual practice is to accept the lot only if the vendor reworks it to make it acceptable or pays for the packager's reworking if the material must be used for rush orders.

Disposition of Rejected Material

When material is found unacceptable, it should be ticketed with a distinctive marker so that it does not leave the quarantine area. The purchasing department should be notified so that negotiations can be started with the vendor and disposition arranged. The accounting department also should be informed so that payment can be held pending settlement of the negotiations. Since the planning department may want to change its schedule or reorder the material, they should receive notice, as well.

Chapter 20— Laws and Regulations

Introduction

Packaging law and its attendant regulations make up a body of information that is now stupendous. However, it is not quite the impenetrable jungle that it might appear to the novice at first sight. It is not possible in this book, however, to conduct a complete discussion of the many details in each regulation. What will be done is to (1) explain the principal regulations and their importance to the field of packaging, (2) document where the important regulatory details can be found, and (3) lay out some guidelines to avoid pitfalls in following rules and regulations on packaging.

Since it's not practical to reproduce here the full text of laws and regulations applicable to packaging, only brief descriptions of the most important sections will be cited to illustrate their regulatory scope. When lifted out of context in this way, such sections of a law may be misleading. So, as any good lawyer would counsel, the reader should consult the very latest and most complete authority on the subject such as the applicable *Code of Federal Regulation* before making any major decision.

Furthermore, since federal regulations are constantly being changed and/or added, a packager also should keep up with the daily *Federal Register,* which publishes proposed changes and final regulations on a continuing basis. Information given in this book is intended only for instructive purposes and is not necessarily to be taken as authoritative over a period of time.

History

The control of manufactured goods in both content and marketing—most particularly foods, drugs, and products of a dangerous nature—has been practiced since antiquity. Egyptian pictographs created in 3000 B.C. show the weighing, marking, and sealing of baled goods. The Romans and Athenians administered quality-control regulation and state approval of packaging for wines and oils in amphorae in A.D. 1. The Arabian government certified measuring cups used to portion products for retail sale in the eighth century markets of the Middle East.

When some governments failed to regulate, industry sometimes stepped in, as in 1819 when London chemists (druggists) established their own labeling regulations to identify dangerous drugs and other chemicals and, hopefully, to lessen the widespread adulteration of virtually everything edible.

However, most early regulations in the world did not have the consumer in mind. Laws, where they existed, were meant to insure that taxes on raw materials and finished goods were paid to the ruling power and that one business person was playing fair with another. That the average citizen lived in a state of *caveat emptor* (let the buyer beware) was nowhere more obvious than in the saloons of England where the poor were served a "gin" in which alcohol was saved by addition of some or all of the following ingredients: turpentine, sulfuric acid, lime, and alum. William Hogarth, the great 18th century satirist and artist, was one of the few who spoke out against this poisonous brew.

Things were not much better in the American colonies and early United States, despite the passage in 1785 in Massachusetts of An Act Against Selling Unwholesome Provisions. This state measure was followed by scattered regulations in other states and territories, but the United States as a whole had to wait 121 years for the first universal regulation of foods and drugs.

The event occurred in 1906 and, as with so many subsequent changes in popular attitude, followed a long period of public anger, capped by a disaster. From the Civil War onward, the American public was increasingly irritated by the prevalence of food adulteration, misbranding, and false advertising. Then, during the Spanish-America War, as casualties grew, investigation revealed that illness and death were occurring more in the army camps around Tampa, Florida, than in the mountains of Cuba. The reason? Bully beef, a major canned ration, had been "embalmed" with poisonous formaldehyde by contract canners to speed the sterilization process.

The public outrage came at a propitious time, since it coincided with the age of "reformers," who ushered in the promising new century. Upton Sinclair's book *The Jungle* in 1900 disclosed horrific truths about the conditions of both the employees and meat products in the slaughter houses of Chicago. This coincided also with the election of Theodore Roosevelt, perhaps the greatest reformer of them all, to the U.S. presidency.

Prior to this, there had been 27 years of effort and the failure of some 200 proposed pure-food measures in Congress. But the continued work of a few dedicated public servants was not to be denied and after months of debate and committee action to resolve differences between Senate and House bills, on June 30, 1906, President Roosevelt signed the first federal Food and Drugs Act "for preventing the manufacture, sale, or transportation of adulterated or misbranded or poisonous or deleterious foods, drugs, medicines and liquors."

Laws are made and funded by Congress, but are useless unless interpreted and administered by some department of the administrative branch of government. Once again, the Age provided an answer in the person of Dr. Harvey Washington Wiley, whose broad background of medicine, chemistry, mineralogy, and agriculture had led him to leave a succession of university professorships to accept the job of chief chemist for the tiny U.S. Department of Agriculture (USDA) 23 years before the food-law battle. Even before the new law was enacted, Dr. Wiley had started studies on food additives and their effects on humans and had joined President Roosevelt and other reformers in the battle for pure-food legislation. The most logical choice was USDA to administer the new law.

As with most initial legislation in new and untried disciplines, the 1906 act was flawed and limited in its effectiveness. But it was the first measure that established the rights of citizens to be protected by their government from undesirable actions and products of industry—a previously unknown concept—that has, more than anything else, come to characterize the 20th century, first in the United States and then in other nations. It was also the first step in the creation of packaging law and regulation, which flowered once again in the 1960s and is still growing and evolving after 90 years of development. As one of its first chief organizers and investigators, Dr. Wiley should surely rank as one of the greatest names in the history of consumer law.

Once begun, the tide of new laws rolled on, propelled by one of the most important aspects of law—precedent. Once a principle has been established, lawyers in future generations are generally bound to honor it, enabling subsequent legislation to proceed much more smoothly.

In this case, first on the list was the addition of meat and poultry to the pure food law shortly after the initial legislation, an accidental and somewhat embarrassing omission. A second important addition was the Shirley Amendment in 1912, which established prosecution for food-law violators and netted 6,000 convictions in the subsequent 10 years. The Virus-Serum Act of 1913 brought animal drugs under the initial law, as well.

Establishment of the Federal Trade Commission (FTC) in 1913 put controls on textile labeling, unfair business practices and slack-filled containers, the latter strengthened by the Standard Container Act of 1916, which defined slack fill more tightly. This judgmatically difficult area of packaging regulations was further solidified by the McNery-Mapes Food Amendment in 1930, which codified package fill requirements and standards for both low and slack fills. Wools and furs were added to the chores of this watchdog group in later years.

A major product of wars always seems to be unique methods of destruction that are immediately turned to civilian use. So it was with the poisonous gases of World War I, which were transformed into pesticides for agricultural and household uses. Coupled with the increasing transport of goods by truck, however, these innovations created new hazards of accidental dispersal in trucking accidents. The result was the Caustic Poison Act of 1921 and the Dangerous Cargo Act a few years later.

By the mid-1930s, however, aging reformers were just about out of ideas for protective legislation when there occurred another of those periodic disasters. In 1937, a defective batch of elixir of sulfanilamide killed 70 people. Growth of technology and the corresponding inadequacies and defects in the pioneering Food and Drugs Act spelled its end.

The ensuing battle between the government and public on one side and the chemical and pharmaceutical industries on the other was long and bruising, but ended in the Federal Food, Drug and Cosmetic Act of 1938 (FDCA) and the establishment of the Food and Drug Administration (FDA). FDA has been called many things—some of them unmentionable—but perhaps the most pertinent was made some years ago during a public lecture by one of FDA's most respected officials. “The Food and Drug Administration,” he noted, “is like a cathedral upon which many little chapels have been grafted from time to time. Perhaps it looks a bit shabby, today, but it still works.” We will see how later in this chapter.

Little known by the general public was a Federal Seed Act in 1939. Of great help to commercial growers, it set standards on the effective germination of seeds. The long-ago precedent, set in a hard-fought battle with commercial seed producers, was resurrected some 27 years later to gain a nobrain victory for the government in determining what data consumers needed on product labels to make informed purchasing decisions. It is the Fair Packaging & Labeling Act of 1966, to be administered by FDA, FTC and the Department of Commerce with penalties for noncompliance.

The activity of the Thirties was the last great gasp of the reformers. A worldwide war and subsequent prosperous peace resulted in a legislative lull of two decades. About the only activity during this period, the federal Insecticide, Fungicide and Rodenticide Act of 1947 (FIFRA), was prompted by the even more exotic chemical developments of World War II. Initially administered by the FDA, FIFRA was later transferred to the jurisdiction of the Environmental Protection Agency (EPA), an administrative body formed as a result of the Toxic Substances Control Act of 1976.

The post-war lull in legislation was broken by another disaster, this time manufactured in a 1955 Milan conference of physicians from around the world, gathered to discuss the reasons for the growing expansion of cancers as a cause of human suffering. Although none of the doctors present, it was reported, were food experts or chemists, a conference conclusion was that food additives could be a prime cause of cancer.

The resultant uproar everywhere, but perhaps most actively in the United States, raged through Congressional hearings, citizen protests, and public debates for three years. The chemical and food industries proclaimed their innocence and the care with which they developed and tested food additives to no avail.

The Food Additives Amendment to the Federal Food, Drug and Cosmetic Act of 1958 was a foregone conclusion and established a new concept in food and drug law that the food processor must prove an additive safe before using it in foods. The processor, naturally, demanded such assurances from its vendors, which in turn, demanded the same assurances from their chemical suppliers. This requirement applies not only to direct food additives, but also to the indirect additives that can be introduced into foods by the materials used to package them. More on this later.

Congress also directed FDA to examine every additive used in foods at that time to establish its safety. In the hearings, FDA had estimated that there were about 704 additives in existence. The eventual list turned up about 3,000. A few of these were discontinued by manufacturers because their volumes of use were too small to warrant the great cost of testing. (In 1959, chemical and animal tests cost about $56,000. Today, such tests easily exceed $2,000,000 and can take several years). It should be noted that of all the additives tested at that time, not one was found to be toxic.

Nevertheless, the half-century of accidental deaths and disclosures dispelled, probably forever, the long-prevailing public belief that industry knew best what was good for the people. The suspicions remain 45 years later and have resulted in such other notable laws involving packaging as the Hazardous Substances Labeling Act of 1960 and its definitive Child Protection Amendment of 1966; Drug Amendments to the FDCA in 1962; the Fair Packaging and Labeling Act of 1966 (FPLA) and its later enhancement, the Nutrition Labeling Education Act of 1990 (NLEA); the Child Protection and Toy Safety Act of 1969; the Poison Prevention Packaging Act (PPPA) and Occupational Safety and Health Acts (OSHA) in 1970, the latter deeded to the Department of Labor for administration; the Hazardous Transportation Act of 1971, which led to the creation of the Department of Transportation (DOT); the Consumer Product Safety Act of 1972 that spawned the

Consumer Product Safety Commission (CPSC), which also absorbed administration of the child protection laws; the Toxic Substances Control Act of 1976 (TOSCA), which created the Environmental Protection Agency (EPA); and the Medical Devices Amendment to the FDCA in 1976, which formalized this agency's control over a huge new branch of the medical industry.

These will be touched upon in this chapter along with such other important regulations affecting packaging as the commercial tariffs, air and ocean packaging requirements, public and private postal services, state regulations, and patent and trademark rules.

Basic Legal Procedure

It is the function of our legislators to determine the need for laws and to draft and enact the statutes that govern our society. They get such information from their own investigations, advisory boards, and other agencies and departments of the executive branch and from citizens and industry groups.

The resultant legislation can originate in the House of Representatives or the Senate or both. To stand a practical chance of success, the concept must have support by one or more powerful legislators, Congressional Committees, and either citizen or industry groups. Of necessity, the resultant law can provide only the broad outlines of policies that have been agreed upon by the federal (or a state) legislature. It cannot cover every situation in detail or anticipate all contingencies.

The responsibility for working out the fine details is usually delegated to an agency of the executive branch, which has been set up for the purpose and, if there is precedent for such responsibility, is so designated by the legislature. The administrative agency then creates a series of regulations that it believes interprets the will of the legislature and publishes the proposed regulations in the *Federal Register,* a document printed five days a week that covers the entire business of the federal government. After a specified amount of time during which those affected by the regulation can submit arguments and proposals, the agency will revise and publish the official regulations in the *Federal Register* and eventually in a specific *Code of Federal Regulations,* a series of from one to many books that are printed at different times, once a year, for every federal agency of government.

Other sources of information on laws are available in the form of agency bulletins and handbooks and from private publishers. However, with respect to the latter, it should be noted that the only information that will stand up in court are the official words that are published by the respective agencies.

A set of regulations then has the force of law, by virtue of the authority delegated to the responsible agency in the law. (In the case of the 1906 law, no such precedent existed, so the executive branch with the cooperation of Congress designated USDA after the law was enacted). To the degree that an agency has correctly interpreted the intentions of the legislature, it is binding upon all concerned.

However, the force of law is useless unless its administration is funded. This is the responsibility of the House of Representatives, which at times has exerted its will by reducing or withholding funds from a particular regulation that it did not favor. In most states, the above procedures are similar.

If, after all of this work, there is still further disagreement by those affected, they can take the matter to an appropriate state or federal court, which is a part of the third branch of government, the judiciary. This step can be a lengthy and expensive procedure, but if justice finally finds for the plaintiffs in either details or in the broad purpose of the law, it must be rewritten or even voided, and the whole process is either dropped or has to start all over again.

Legal action is not uncommon on controversial laws and regulations. In the case of the FDA, however, swifter and less costly justice is available through informal hearings with the agency or one of its expert panels or by formal FDA hearings or judgements by one of its administrative law proceedings, a sort of in-house court that requires acquiescence by the plaintiff that it will accept the administrative law judge's ruling.

Packaging Regulations

It has been estimated that some 2,000 federal regulations have an impact upon packaging, not to mention the various different state regulations that also come to bear. As a result, all packaging management personnel, designers, technologists, and engineers should be at least familiar with the regulations that impact their products and industries and should have on tap lawyers with a depth of knowledge of both state and federal packaging law.

From what has already been said, it is obvious that the *Federal Register* and up-to-date copies of the applicable *Codes of Federal Regulations* should be familiar reading to some packaging technologist in every packaging company as well as with most packaging vendors. In general, these regulations influence four broad categories: (1) weights and measures; (2) adulteration; (3) public safety; and (4) information. A fifth category of environmental regulation has appeared in recent years and will be discussed in Chapter 21, Packaging and the Environment.

Weights and measures laws are designed to ensure that the purchaser knows the terms of his purchase and that he receives full value for his money. The customer must not be deceived or misled by the shape or size of a package.

Laws related to adulteration are primarily concerned with the wholesomeness of the product, and only incidentally with the part played by the container. However, materials and the construction of the package must not change the product nor add any foreign material to it which could cause it to change. This is very important for food products and even more critical for drugs, which must be precisely defined in content and given government approval before marketing.

Public safety is often connected with hazardous chemicals in distribution, as well it should be. However, today the packaging concern also extends to packaging components involved in protecting children from hazardous chemicals and drugs while still enabling access by elderly citizens. The safety issue also extends to packaging machinery in plant operations. These requirements are increasingly being enforced.

Information, one of the basic functions of packaging, describes the product, its virtues, and methods of use; its cautions, if possessed of a hazardous nature; and the amount and type of product present in a container. The package itself, therefore, provides the main billboard for disseminating these details.

Many laws cover several functions of a package. Therefore, we will describe each major federal regulation governing packaging independently, noting any multiplicity of task where it occurs. It should also be remembered that states have their own regulations, as well, and although many parallel the federal rules, some are quite different. Occasionally, state regs will take precedence over federal law. However, in most cases a federal law will preempt (overrule) equivalent state laws. Laws and regulations of direct concern to the safety and convenience of the public will be addressed first, followed by the laws and regs that primarily affect industry.

Weights and Measures

Weights and measures regulations, a fundamental requirement in packaging, are the responsibility of the individual states. Most follow the provisions of the Model State Weights and Measures Law of 1965, drafted at a conference of state representatives held by the Department of Commerce's National Bureau of Standards. This measure is voluntary, but designed to encourage more uniformity throughout the country.

States were granted power to control the packaging and distribution of goods within their boundaries by Congress in 1836. Since then, a vast number of individual laws and regulations have arisen. States believe that the fulfillment of federal packaging laws, which only govern goods moving in interstate commerce, does not exempt packagers from complying with state laws. Although some recent federal legislation does preempt all state laws of its kind, the existence of multitudes of other state regulations, most particularly weights and measures requirements, is a fact of life that should not be ignored by packagers in planning their packaging.

Foods, Drugs, and Cosmetics

Foods, drugs, and cosmetics regulations are basically three major and different sets of regulations covered by the same legal Act, as amended. While there are certain similarities among the three areas, there also are major differences. Therefore, they will be discussed separately.

Food Regulations

The primary purpose of food regulation is to insure a safe and properly identified range of products for human consumption. The basic law is administered by FDA (see Table 20.1 for details on where to find the major food regulations in CFR 21, Food and Drugs). Meats and poultry are under the jurisdiction of USDA (see page 629).

It should be noted that these regulations cover food products in interstate commerce. Foods produced and consumed within a state are the responsibility of the state. Most states have their own food and drug agencies, which vary considerably in capability.

The federal law and regulations prohibit the manufacture, introduction, or receipt of adulterated or misbranded products. An adulterant is a poisonous or deleterious substance. Misbranding is false or misleading labeling.

Inspectors from the FDA can and do examine products on the market and are permitted to inspect food-processing plants, which are operated under an FDA-recommended plan of Current Good Manufacturing Practices (CGMPs). These cover the appearance and training of employees and the sanitation of plant grounds, operations, equipment and controls, and the efficacy of processing times, equipment, and test procedures.

Failure to follow such procedures can evoke fines, and continued mistakes can result in emergency permit control of operations by FDA or even a shutdown of the facility. The FDA also can seize adulterated or misbranded food and hold it for further legal action.

Additives to food products must be cleared by FDA. Additives are any substance that can reasonably be expected to become a component or affect the characteristic of a food, a definition stated by the famous Delaney Clause in the Food Additives Amendment of 1958. This clause is troublesome now that technology is capable of detecting substances in a few parts per billion, a level at which almost everything is contaminated with a tiny bit of every-

TABLE 20.1. Key Regulations for Human Foods (Title 21—Food and Drugs, CFR 21, Chapter 1).

Parts	Regulations
	SUBCHAPTER A—General
1–16	General enforcement, rulings, jurisdictions, enforcements, practices, and hearings
58	Good laboratory practice for nonclinical studies
70–82	Color additives, petitions, exemption from required certification, certification procedure, general specs, restrictions for use in foods, drugs and cosmetics, listing of certified colors
	SUBCHAPTER B—Food for Human Consumption
101–107	Food labeling, usual names, quality and nutritional guidelines, infant formula and control procedures
108	Emergency permit control
109	Unavoidable contaminants in food and packaging materials
110	Current good manufacturing practices (CGMPs)
113	Thermal processing of low-acid foods
114	Acidified foods
123–169	Definitions, standards, CGMPs, hazard analysis and plans, records, training, and sanitation for a broad range of fish, water, milk, cheese, dessert, bakery, cereal, pasta, canned fruits and vegetables, juices, beverages, frozen vegetables, egg products, nuts, margarine, sweeteners and syrups, food dressings and flavorings
170–173	Direct food additives, petitions and their addition to foods
174–178	Indirect food additives and their sources in adhesives, coatings, paper and board components, polymers and adjuvants, production aids, and sanitizers
179	Irradiation in production, processing, and handling of foods
180–186	Prior sanctioned food ingredients and other substances generally regarded as safe, direct food substances generally recognized as safe, indirect food substances generally regarded as safe
189	Substances prohibited from use in human food
197	Seafood inspection program

thing else. The Delaney philosophy has been largely bypassed today by FDA determination of what is an attainable freedom from toxicity and whether that level is safe.

Direct additives are those purposefully added to a food. To be permitted, they must have a utile reason for inclusion and the petition must incorporate data on the additive's history, composition, stability, method, and quantity to be used; manufacturing data; control procedures; and animal feeding tests.

How to Locate, Read and Interpret CFR Regulations
Codes of Federal Regulations (CFRs) are divided into chapters, subchapters, parts and subparts, which describe major divisions of the regulations for any given law. Parts and subparts are further divided into numbered and lettered sections that provide the details. At first look, locating desired information may seem complex, but it really is not.
For example, take CFR 21, Food, Drugs, and Cosmetics, which is a series of nine manuals, the first eight titled Chapter I, The ninth, Chapter II, SUBCHAPTER A starts with general information and the locations in the CFR of important requirements about the regulation, precise definitions of important words and terms, and a citation of the authorities by which FDA is permitted to regulate the subject products, typical for any CFR.
SUBCHAPTER B is about "Food for Human Consumption." This is followed by Part numbers that head every important section to every major element of the regulation. As an example, take Part 170, which refers to "Food Additives." This, in turn, is divided into various regulations concerning food additives. For example, Subpart B refers to "Food Additive Safety" and each element of that subject is further identified by a subdivision of the overall Part number. From the CFR:
SUBCHAPTER B-FOOD FOR HUMAN CONSUMPTION
Part 170-FOOD ADDITIVES
Subpart A-GENERAL PROVISIONS
170.3 Definitions
170.6 Opinion letters on food additive status
170.10 ……..
Subpart B-FOOD ADDITIVE SAFETY
170.20 General principles for evaluating the safety of food additives…
Major subdivisions of the major Part number are placed to the right of the period, e.g., 170.3, 170.6, etc. These numbers are not decimals, but simply indicate a numerical sequence of regulatory or explanatory material that can sometimes run into the hundreds.
Primary subsets of these Part number divisions start out with a lowercase letter in parentheses, as (a). Secondary subsets start with a number in parentheses, as (1). Further subsets use roman numerals expressed in lowercase letters, as (i), (ii), (iii), (iv). Any further subsets then revert to lowercase letters, (a), (b), etc. In a rather extreme case, a point to be located could be entitled 170.38(c)(l)(i)(a). To find this reference, scan through Subpart B-Food Safety. The above reference simply states that "(c)(l) Persons seeking affirmation of GRAS status … shall submit a petition … that shall … establish GRAS criteria … in the following form: (i) description of the substance, including: (a) common or usual name."
It should also be noted that certain Part numbers or even significantly large sections in many CFRs are marked [Reserved], a precaution so that room is available for future regulative rewriting or expansion.

FDA can then allow unrestricted use, controlled use in specific foods, or ban it altogether. After the Food Additives Amendment became law, existing additives were evaluated by a large panel of experts and divided between those Generally Recognized As Safe (GRAS) and those that required additional testing. This GRAS list is periodically updated.

Indirect additives are those substances that migrate to a food product from plant processing equipment, the packaging material, or any other source. Such additives must be proven safe and their presence in the product must be controlled to the smallest possible amount.

FDA has long been in the information process of packaging with label requirements for product identification and origin. This role was heightened by the FPLA and its detailed specification of what consumer use information is required on a package, where it is to be positioned, and even in what type size it should be printed.

This has been infinitely increased by NLEA, phased in over four years, which requires mandatory nutritional information on most foods, including serving sizes and servings per container, total calories per serving, and the "Percent of Daily Values in each particular food of such nutritional elements as total and saturated fats, cholesterol, sodium, carbohydrates, and proteins and the percentage of daily needs for vitamins A and C, calcium, and iron. Some of these measurements are still subject to public and professional criticism, but at least the law has enabled a reasonably intelligent consumer to ascertain a food product's nutritional worth, which was not uniformly possible in the past.

This relatively new law has naturally spawned labeling claims of superior value for products with low or zero product contents of fat, sodium (salt), sugar, and cholesterol and, in some cases, for products with not so low contents either. As a result, FDA and FTC are monitoring dietary and promotional labeling statements and descriptions, respectively, and will ban unacceptable claims. Some states also have followed suit.

More recently, FDA's jurisdiction has been broadened to include seafood. It is continuing the formulation of inspection and regulatory procedures for these delicate and important nutritional items. These products were originally in the jurisdiction of Public Health, a federal department that created model sanitary legislation for state and local boards of health (like the model weights and measures law of the Department of Commerce). Public Health was absorbed by FDA some years ago.

For a greater study of FDA food and packaging requirements, see Table 20.1, which lists the most important Part Numbers for food regulations in CFR 21 Food and Drugs. To better understand how to use and understand the numbering system in all CFRs, see How to Locate, Read, and Interpret CFR Regulations, page 617.

Drug Regulations

The general principles of regulatory control for drugs is about the same as for foods, although pharmaceuticals require a higher degree of regulation and control. Drug standards are contained in the *United States Pharmacopeia-National Formulary (USP-NF),* a compendia published periodically with interim supplements by The United States Pharmacopeial Convention, Inc.; 12601 Twinbrook Parkway; Rockville, MD 20852.

Sometimes called the Pharmacopeia for short, the *USP-NF* is actually a merged publication. The *USP* portion, established in 1817, applies to drug products, while the *NF,* published by the American Pharmaceutical Association prior to 1974, covers drug ingredients.

The *USP-NF* defines each drug in use and specifies in general terms the type of package in which it should be contained. There is also a long table designating the types of containers for re-packaging tablets and capsules ranging from tight to well-closed to light-resistant, as applicable. The *Pharmacopeia* also contains a reprint of the FDA CGMPs for drugs.

Drugs must not differ in identity, strength, or purity. They must be packaged according to official directions and drugs that deteriorate must be enclosed in FDA-established packages. Virtually all consumer drug packaging must have closures that are resistant to opening by children in keeping with the PPPA, which also applies to other dangerous household chemicals. OTC drugs also must have tamper-resistant packaging (see page 620).

New and investigational drug applications (NDAs and INDAs) must be filed with FDA and must establish the drug safety under stipulated conditions. The report must also include preclinical studies, establish effectiveness and composition, stipulate manufacturing and packaging methods (CGMPs), and be accompanied by drug samples, containers, labels, and promotional materials.

Foreign firms, which export drugs to the United States, also must register with FDA and meet the same requirements for submission of data.

An approved drug is given an official designation by FDA called a National Drug Code (NDC). The drug manufacturer is also issued a registration number for each plant, which must be reregistered annually. Manufacturers are subject to FDA inspection at least once every 2 years.

CGMP regulations, which are updated regularly and have the effect of law in drug manufacture and packaging, now apply to both ethical (prescription) drugs and over-the-counter (OTC) compounds.

Computers are permitted in manufacturing and packaging, but also require hard-copy backup. The regulations not only specify precise sanitary procedures but also employee clothing, tight inventory control on packaging components, quarantine for incoming packaging inspection, removal of all remaining product and packaging from a line before the next run, and written procedures for all production packaging operations.

Any serious mistakes in the above procedures can cause a recall of product by FDA. In 1994, procedures for these actions were modified by establishment of three classes of defect hazards with definitions: Class I poses a serious threat to the public health requiring removal of product from the market down to the individual consumer level and accompanied by a public warning; Class II describes a potential hazard with product removed to the retail level; and Class III is a law violation with remote health hazard and removal of product to the wholesale level.

It was an increase in such recalls involving mislabeled drugs in recent years that produced a recommendation from FDA for the employment of electronic means for the 100 percent inspection of labeled products and a strong push toward the elimination of cut labels in favor of rollstock labels for the identification of pharmaceuticals [1].

Biologicals (blood components, bacterial, viral, and dermal diagnostic substances) and antibiotics have even tighter standards of manufacturing and packaging than the chemical drugs. These compounds were originally handled during their developmental period by the National Institutes of Health, Division of Biological Standards, which was absorbed by FDA in 1972.

For many years, OTC drugs, vitamins, and minerals proceeded with little attention from FDA. However, the Drug Amendments of 1962, which for the first time required all drugs to be safe and effective by scientific study, also confirmed FDA's formal authority over OTC compounds, including their advertising and enabled an extensive review of these products. Since then, FDA has enacted stricter control, particularly over promotional claims for both OTC drugs and vitamins and minerals.

Regulations for animal drugs and foods are closely akin to those for human drugs and foods and are covered in CFR 21, Food and Drugs (see Table 20.2). To understand how to use a CFR, see How to Locate, Read and Interpret CFR Regulations on page 617.

Tamper-Evident Packaging

In September and early October of 1982, seven people in the Chicago area died of potassium-cyanide poisoning resulting from adulterated capsules of Extra-Strength Tylenol, a product produced by the McNeil Consumer Products Div. of Johnson & Johnson, Ft. Washington, Pennsylvania. There had been tamperings before and there would be incidents afterward. But, never has a packaging emergency drawn swifter and more comprehensive action.

While McNeil removed every container of Tylenol capsules from the national market and examined each for safety, the FDA produced and published in slightly over a month a regulation calling for the protective packag-

TABLE 20.2. Key Regulations for Human and Animal Drugs (Title 21—Food and Drugs, CFR 21, Chapter I, II, and IV).

Parts	Regulations
	SUBCHAPTER C—Drugs
200	General
201, 206	Labeling requirements and claims for prescription and OTC drugs and imprinting for solid oral-dosage drugs
207	Registration of drug producers and drugs in commercial distribution
210–250	CGMPs for manufacturing, processing, packing, or holding of drugs, general; for finished pharmaceuticals, medicated feeds, Type A medicated articles, and special requirements for specific human drugs
290	Controlled drugs
291	Drugs used for treating narcotic addicts
299	Drugs: official and established names
	SUBCHAPTER D—Drugs for Human Use
300	General
310–329	New drugs, investigational new drug application, application for FDA approval to market new drugs and antibiotics, orphan drugs, bioavailability and bioequivalence requirements, oral OTC drugs that contain alcohol and habit-forming drugs
330–358	OTC drugs recognized as safe, effective, and not misbranded; antacids, antiflatulents, topical antimicrobials, antiemetics, sleep aids, and stimulant drugs, cold, cough, allergy, bronchodilator, anti-asthmatics, topical OTICs, anorectals, skin protectants, external analgesics, ophthalmics, anticaries, misc. internal and external OTCs
361	Prescription drugs recognized as safe, effective and not misbranded; drugs used in research
369	Interpretive statements about warnings on OTC drugs and devices
429	Drugs composed wholly or partly of insulin
430–436	General, certification, packaging, and labeling, exemptions from certification and tests, and method of assay for antibiotics and antibiotic-containing drugs
440–460	Penicillin, penem, cepha, carbacephem, oliosaccharide, tetracycline, peptide, antifungal, antitumor, macrolide and lincomycin antibiotics, certain other antibiotic drugs and antibiotic drugs intended for laboratory disease diagnosis
	SUBCHAPTER E—Animal Drugs, Feeds, and Related Products
500	General
501–505	Animal food labeling, common or usual names for nonstandardized animal foods and interpretive statements about warnings on OTC animal drugs

(table continued on next page)

TABLE 20.2. (continued).

Parts	Regulations
507	Thermally processed low-acid foods packaged in hermetically sealed containers
508	Emergency permit control
509	Unavoidable contaminants in animal foods and food-packaging materials
510–529	New animal drugs, drugs for investigational use, new animal drug applications and implantation, injectable, ophthalmic, topical, intramammary, and other dosage forms for new animal drugs
556–558	Tolerances for animal drug residues in foods and new animal drugs for use in foods
564–571	Definitions and standards for animal food, food additives, and food additive petitions
573–584	Food additives permitted in animal feed and drinking water; irradiation in production, processing and handling of animal and pet foods; substances generally recognized as safe; and substances affirmed as safe in feed and drinking water
589	Substances prohibited from use in animal food or feed
	SUBCHAPTER F—Biologics
600–601	Biological products, general and licensing
606	CGMPs for blood and blood components
607	Establishment registration and product listing for manufacturers of human blood and blood products
610–680	General biological products standards and additional standards for bacterial products, viral vaccines, and human blood products, diagnostic substances for dermal and laboratory tests, and other miscellaneous products
	Chapter II
	Drug Enforcement Administration, Department of Justice
	Chapter IV Office of National Drug Control Policy
1301	Registration of manufacturers, distributors, and dispensers of controlled substances
1302	Labeling and packaging requirements for controlled substances
1303–1308	Quotas, records/reports of registrants, order forms, prescriptions, exceptions, disposal, special exemptions and schedules for controlled drugs
1309–1313	Application, registration, and exemptions for manufacturers, distributors, importers, and exporters of controlled substances and precursors and essential chemicals
1316	Administrative functions, practices and procedures

ing of almost all OTC human drugs sold at retail except ammonia inhalants in crushable glass ampules, aerosols, containers of compressed medical oxygen, dermatologic, dentifrice, insulin, or throat lozenge products [2].

The regulation, contained in the Drug Packaging and Labeling Control section, is termed “tamper-resistant.” However, it is generally accepted that any package can be tampered with and that what is really presented to the consumer is a tamper-evident (TE) device that requires the attention of the consumer to determine its status.

The regulation specifies that a TE package has one or more barriers to entry, which, if breached or missing, will provide visible evidence to consumers that the package has been violated. The package can be distinctive in design, like an aerosol, or have barriers to entry that employ an identifying design that cannot be reproduced by commonly available materials or processes. The TE feature(s) may be located on the primary or secondary container or any combination of the two and must be accompanied by a printed statement that draws attention to the nature of the device. In addition, because capsule products have been associated with a number of tampering incidents (and deaths), two TE features are required on this dosage form, one of which can be sealing of the capsule itself [3]. TE features must be resistant to damage by normal handling and transport practices.

While foods have not as yet been compelled to provide TE packaging, the number of the containers on the market that do carry this safety feature are steadily increasing in numbers and in ingenious designs that bring costs down within the reach of food products (see Figure 20.1).

As any lawyer would point out, it has already been determined that tampering is a likely occurrence and that a substantial number of product manufacturers use one, two, or three devices to protect their products. Therefore, foods without a TE device are vulnerable to court actions even though not covered by a regulation.

Among the simplest TE devices for bottles is a heat-sealed and distinctively printed inner seal that covers and is attached to the bottle finish so firmly that it must be torn away to open the bottle and access the contents. Its presence, however, is not visible from the outside at the point of purchase.

A simple closure device, which is visible at point of purchase, is the breakaway cap. It is held onto the container by a perforated bottom section that fits over a raised ring in the bottle finish. The main part of the cap must be twisted to break away from this bottom section in order to open the container. Shrinkable film capsules or bands also are used to secure bottle and jar closures (see Figure 20.1). Many other styles are available, too, such as the one used for gabletop cartons and shown in Figure 20.2.

Figure 20.1.
Although not required by law, more and more food products are adding TE devices like this custom-printed heat-shrinkable polyvinyl chloride neckband. Three-color reverse printing features company logo and tag line. (Source: Seal-lt, Inc., Farmingdale, New York, used with permission.)

Another device is an adhesive- or heat-sealed label that passes over the closure, adhering both to it and to the wall of the container. Twisting the closure, breaks the seal or the label may have a perforated tear strip located over the joining of cap and bottle.

Cartons can be closed with hot-melt adhesive and so constructed that opening irretrievably tears a tab or flap to pieces. Shrink-film wraps with distinctive designs and bead-seal seams are another protective carton device. More elaborate is a specially coated shrink-film that covers a carton with one or more specially-printed and invisible panels at key positions. The heat shrinking causes the film to adhere to these panels. Film removal peels off a top ink layer in the panel areas to reveal the under-printed word "opened."

Cups, like those used for sour cream, are generally secured with a brittle plastic band over the lid and cup edges that fractures the minute it is peeled. A second choice is a stronger plastic band over the edges that generally must be severed with scissors or a knife to separate cup from lid. There is a proliferation of other devices as well.

An area of great concern and package development, today, is the TE protection of unit dosages of capsules or tablets in shallow thermoforms with a foil lidstock over the dispensing side. Formerly little used in the United States, these blister packages are now gaining volume.

Another concern is the capability of physically handicapped citizens to open either TE or child-resistant (CR) closures—or closures possessing both features—which are used with almost all OTC drugs, home-dispenser vials for prescription drugs, and some dangerous cosmetic products. CR regulations will be discussed later under the CPSC section.

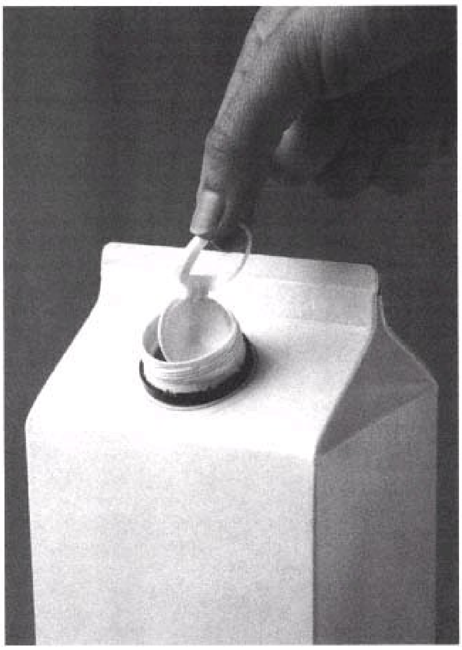

Figure 20.2.
Double TE protection is provided by EL fitment for 1-L, 2-L, half-gal, and qt gabletop cartons. To open, consumers twist the closure to break the TE band, which remains with the container, and then pulls out the internal molded membrane seal.
(Source: Portolla Packaging, Inc., San Jose, California, used with permission.)

Medical Devices Regulations

Medical devices are the third major division of FDA, officially incorporated by the Medical Devices Amendment of 1976 after the agency and Congress suddenly discovered that a quietly growing industry had burgeoned into thousands of items, instruments, and diagnostic tools with minimal or no organization and little regulation.

As a result, devices have been separated into three classes: Class 1, subject only to general controls; Class 2, which has performance standards on construction; and Class 3, covering life-support and implanted devices, which require pre-marketing clearance. A major problem in the categorization of devices is that with improvement and innovation, specific items or groups have had to be moved from one class to another with some frequency. More stability in this structure is now being attempted both by FDA and industry.

FDA has recently revised the CGMPs for devices, incorporating them into a total quality-system regulation. The new system specifies that packaging must protect the device from any alteration or damage; that printing, storage, handling, and application of labels is done in such a way as to prevent label deterioration and mix-ups; and that records must be kept of the distribution chain through which each device passes.

A manufacturer also must keep a history of device manufacture, changes, packing, shipping, and complaints. FDA can bar the marketing of a device that is deceptive or poses an unreasonable public risk (see Table 20.3 for significant device regulations in CFR 21, Food and Drugs).

Cosmetic Regulations

Cosmetics have been an orphan in FDA regulation because of resistance from both manufacturers and customers alike. These products must comply with the general FDA rules on safety of the container and products. In the 1970s and 1980s, FDA did manage to ban the use of such hazardous chemicals as mercury compounds, vinyl chloride, methylene chloride, and chloroform in cosmetics and chlorofluorocarbon propellants and zirconium complexes in cosmetic aerosols.

FDA also requires an aerosol label warning covering hazards to the eyes, incineration and inhalation prohibitions, and a special warning on skin sensitivity for feminine hygiene deodorant sprays. Hair preparations containing coal tar dyes, which pose a risk of cancer, must carry a warning statement. Producers also must use TE packaging on liquid oral hygiene products and vaginal products for retail sale.

Using FPLA as a wedge, FDA has insisted on ingredient statements in descending order of predominance (as with foods), but requires only the generic statement, “fragrances and flavors,” rather than the specific names of such “secret” compounds. Acceptable names for other ingredients have

TABLE 20.3. Key Regulations for Medical Devices (Title 21—Food and Drugs CFR 21, Chapter 1).

Parts	Regulations
	SUBCHAPTER H—Medical Devices
800	General
801	Labeling
803–804	Medical device and distributor reporting
805	Cardiac pacemaker registry
807	Establishment registration and device listing for manufacturers and distributors of devices
808	Exemptions from federal preemption of state and local medical device requirements
809	In vitro diagnostic products for human use
812–813	Investigational device and intraocular lenses exemptions
814	Premarket approval of medical devices
820	General GMPs for medical devices
821	Medical device tracking requirements
860	Medical device classification procedures
861	Procedures for performance standards development
862	Clinical chemistry and toxicology devices
864–892	Hematology, pathology, immunology, microbiology, anesthesiology, cardiovascular, dental, ear-nose-and throat, gastroenterology-urology, plastic surgery, hospital and personal use, obstetrical-gynecological, ophthalmic, orthopedic, physical medicine, and radiology devices
895	Banned devices
	SUBCHAPTER I—Mammography Quality Standards Act
900	Mammography
	SUBCHAPTER J—Radiological health
1000	General
1002	Records and reports
1003	Notification of defects or failure to comply
1004	Repurchase, repairs, or replacement of electronic products
1005	Importation of electronic products
1010–1050	Performance standards for general electronic products and ionizing-radiation-, microwave, and radio-frequency emitting, light-emitting, sonic, infrasonic, and ultrasonic radiation-emitting products

been established and are available from the Cosmetic, Toiletry and Fragrance Association, Washington, D.C.; The United States Pharmacopeial Convention; and from FDA. Where cosmetics are also a drug, the listing of these ingredients must precede those of the cosmetic. Where a cosmetic product is too small for such listings, a firmly attached separate label or tag may be used.

FDA may request premarket testing of new products, but if a manufacturer refuses then it must print a label warning regarding lack of safety testing. Most producers, however, do perform compatibility and safety testing.

Some years ago, FDA started a voluntary registration program among producers to tabulate classes of cosmetics and toiletries by ingredients to determine GRAS status, toxicity, and safety criteria and also to voluntarily report cosmetic product experiences. The response reportedly has been poor. Later, FDA proposed mandatory hypoallergenic pretesting, but lost the action in a court case.

The regulatory weakness in cosmetics, despite FDA's strength in other areas, stems largely from the fact that the cosmetic regulations are virtually unchanged from the much weaker original 1938 FDCA. FDA can establish product, package, and labeling standards and exemptions, but it must prove a lack of safety or toxicity of a cosmetic product **before** acting on the industry—a throwback to the original 1938 law. Congress has given FDA greater power in all other aspects of the law, but it is known that women, by and large, resist any tampering with their personal products, a fact that came out during hearings on additives in the late 1950s. Now, Congress knows a political minefield when it sees one. See Table 20.4 for major cosmetic regulations in CFR 21, Food and Drugs.

Miscellaneous FDA Regulations

There are six other bodies of regulations for which FDA is also responsible.

Under the Federal Import Milk Act of 1927, FDA must inspect imported milk and cream for purity and quality and even the foreign dairy herds and plants and pasteurization facilities for sanitation [4]. FDA then issues a permit to such import sources allowing admittance of these products into the United States.

The same requirements are extended to teas under the Tea Importation

TABLE 20.4. Key Regulations for Cosmetics (Title 21—Food and Drugs 21 CFR, Chapter I).

Parts	Regulations
	SUBCHAPTER G—Cosmetics
700	General
701	Cosmetic labeling
710–720	Voluntary registration of cosmetic product establishments and filing of ingredients and raw material composition statements
730	Voluntary filing of cosmetic product experiences
740	Cosmetic product warning statements

Act of 1920 as amended in which the imported products are held under bond until inspected and approved by the agency [5].

The ancient Caustic Poison Act of 1921, most of which has been superseded by later legislation, is still in force for the control of imported caustic or corrosive substances and their proper packaging and labeling [6]. While FDA does the examination and testing, the District Directors of Customs function to detain, store, and dispose of any chemicals that do not meet requirements.

FDA also has a role through its public health function in the control of communicable diseases by assisting state and other federal bodies in the detection and apprehension of persons carrying communicable diseases and in inspection of interstate shipments or imports of certain seafood, animals, birds, and other objects, which can be receptive to pathogenic organisms [7].

General requirements for the purity of drinking water, mandatory pasteurization of all milk and milk products, and treatment of garbage in interstate traffic are also under this jurisdiction as is the sanitation of interstate vehicles and vessels used for land, water, or air transport of foods in foodservice operations [8].

Stored human tissue intended for use in living human beings is also under the supervision of FDA with respect to the people, facilities, processing, and storage involved [9].

U.S. Department of Agriculture

When the original food law was passed in 1906, the president and Congress more or less informally handed its administration to the USDA. However, when Congress woke up to the fact that it had forgotten to specifically cover meats, the main reason for the initial turmoil, and then passed the Meat Inspection Act of 1907, it officially designated USDA as the body responsible for inspection and labeling of meats and, 5 years later, poultry.

Thus, in 1938, Congress felt easy in creating a new bureau for foods, drugs, and cosmetics, but honored its previous precedent by leaving meats and poultry with USDA. Ever since, there has been agitation to move meats and poultry to FDA as a matter of regulatory efficiency and economy, but it seems unlikely to happen. However, as government agencies go, the two bodies cooperate reasonably well in their respective interplays.

USDA governs the accumulation, slaughtering, and mandatory inspection and packing of meat animals under the Meat Inspection Act of 1907 and the Packers and Stockyards Act of 1921 and mandatory inspection of poultry under the Poultry Products Inspection Act of 1957. It also administers the use of food additives, packaging, and labeling requirements for these products to comply with the FDCA. USDA also administers the production and packaging of certain animal biological products in accordance with the Virus-Serum-Toxin Act of 1913.

In addition, USDA operates a voluntary fee-for-service inspection operation of both fresh and processed fruits and vegetables and such other foods as nuts, sugars, syrups, teas, coffees, spices, and condiments under the Agricultural Marketing Act of 1946. For processed products, the inspection service can be continuous with an inspector located at all times in the processing plant or "pack grade," whereby processed samples are drawn after packaging. In either case, plant inspections are done to insure that the plant and product are clean, safe, and wholesome, are truthfully and accurately labeled, and meet applicable specifications for filling and/or drained weight—all to the specifications of FDA CGMPs. The product grading is done to U.S. Grade Standards of A, B, or C, established by USDA, which permit the packager to show the applicable shield or grade statement on the product label.

The service also can be used by packers to examine food containers from the primary to the distribution packages for defects and their severity. See Table 20.5 for detailed USDA regulations in CFR 7, Agriculture and CFR 9, Animals and Animal Products.

Federal Trade Commission

FTC responsibilities, organized in 1915 by the Trade Commission Act of 1914, are "to administer a variety of statutes…designed to promote competition and protect the public from unfair and deceptive acts and practices in the advertising and marketing of goods and services." The Commission is composed of five members appointed by the President and confirmed by the Senate for terms of seven years.

The Commission has an enforcement role in several regulatory laws involving packaging and creates an astonishing number of guidelines for industries, the application of which enables them to avoid unlawful trade practices.

FTC's roles in packaging generally are related to deceptive or unfair competitive actions, but the FTC also has broad responsibilities for the labeling of many goods in the field of fabrics, furs, and the like.

This agency generally does not seek out infractions of its regulations, except in cases of descriptive labeling of textile products. In most other areas, it acts only upon the request of individuals or companies that feel deceptive or unfair methods are being used.

A slack-filled container, for example, is considered deceptive if it has a false bottom or an excessive amount of headspace or cushioning. No specific amount has been established as excessive, but 15 percent is often taken as an upper limit for headspace with liquid products.

The FTC has a role under the FPLA and NLEA too. With the exception of foods, drugs, and cosmetics, FTC is responsible for making sure that all products are identified by type and form, size and material, and manufac-

TABLE 20.5. USDA Regulations for Fresh and Processed Fruits, Vegetables, Meats, Poultry, and Grains and Processed Fruits and Vegetables (CFR 7, Agriculture, Chapter I).

Parts	Regulations
	SUBCHAPTER A
42–43	Standards for condition of food containers
	Subparts A to E, general and procedures for stationary lot and on-line sampling plans
	SUBCHAPTER B
46–51	Regulations and rules of practice for the inspection of fresh fruits and vegetables under the *Perishable Agricultural Commodities Act of 1930*
	SUBCHAPTER C
51	Regulations, inspection, and standards for fresh fruits, vegetables, and other products under the *Agricultural Marketing Act of 1946*
52	Regulations, inspection, and standards for processed fruits, vegetables, and other processed food products
	CFR 9, Animals and Animal Products, Chapter I
	SUBCHAPTER E—Viruses, Serums, Toxins, and Similar Products
109–113	Sterilization, pasteurization, packaging, and labeling and standard requirements
	CFR 9, Animals and Animal Products, Chapter III
	SUBCHAPTER A—Mandatory Meat Inspection
301–311	Definitions, inspection application, exemptions and violations, inspection facilities, sanitation, ante- and post-mortem inspections, human slaughter, and disposal or rendering of condemned or renderable parts
316–320	Marking products and containers, labeling and marking devices and containers, definitions and standards of identity, records registrations, and reports
335	Rules of practice under the Federal Meat Inspection Act of 1907, as revised and amended
	SUBCHAPTER B—Voluntary Inspection and Certification
350–362	Special services, exotic animals and rabbits, certified products for pets, voluntary poultry inspection
	SUBCHAPTER C—Mandatory Poultry Products Inspection
381	Poultry products inspection regulations
	Subpart M—Official marks, devices, and certificates
	Subpart N—Labeling and containers
	Subpart P—Definitions and standards of identity
	Subpart Q—Records, registration, and reports
	Subpart X—Canning and canned products

turer or distributor. FTC also governs the use of promotions and free offers for retail goods, the number permitted per year by a manufacturer, and also determines whether such deals are legitimate.

In the relatively new nutritional labeling area, FTC is, with FDA, keeping an eye on the nutritional claims made by packagers and setting standards for the descriptions of these claims (see Table 20.6).

Department of Commerce

The Department of Commerce's role under FPLA was to push for reductions in the number of differently packaged quantities of a product on the market, a role that has been quietly forgotten.

Consumer Product Safety Commission

The CPSC was formed in 1973 under the Consumer Product Safety Act to protect the public against unreasonable risks of injury associated with consumer products, to assist consumers in evaluating the comparative safety of

TABLE 20.6. Key FTC Regulations for Product Claims (CFR 16, Commercial Practices).

Parts	Regulations
	SUBCHAPTER B—Guides and Trade Practice Rules
17–260	Guidelines on prohibited practices or claims on packages, labels, and in advertising of a wide range of products
	SUBCHAPTER C—Regulations Under Specific Congressional Acts
300–311	Guides and trade practice rules as above for woolens, furs, textile fibers, and other specific products and their packaging and labeling identification
	SUBCHAPTER D—Trade Regulation Rules
403–460	Guides and rules as above for another listing of products and their packaging and labeling identification
	SUBCHAPTER E—Rules and Regulations under the Fair Packaging and Labeling Act of 1966
500–503	A listing of the provisions of the above Act and the role of the FTC in working with FDA, particularly in Parts 502 and 503, to assure fair representation of package sizes, ingredients, fill levels, and product claims. FTC also has issued in Part 503 a listing of common products not to be considered as consumer commodities within the meaning of the Act.

such products, to develop safety standards for consumer products, and to promote research into the causes and prevention of accidents with consumer products. It administers five other laws: the PPPA, the Hazardous Substances Act of 1960, the Child Safety Protection Act, the Refrigerator Safety Act of 1956, and the Flammable Fabrics Act of 1953. Only the first two have a measurable packaging role.

The Commission is composed of five members appointed by the President and confirmed by the Senate for seven-year terms. There are three regional centers in the East, Midwest, and Far West. The Commission relies heavily on advisory committees of public experts for its studies and opinions leading to regulatory actions.

CPSC can ban distribution of products that have been judged too dangerous for public circulation. It also can exempt a class of products from the regulations or request that a U.S. District Court seize an imminently dangerous consumer product that poses an unreasonable risk of injury, serious injury, or death.

Under the Consumer Product Safety Act, CPSC requires a warning label on aerosols powered by chlorofluorocarbon (CFC) propellants notifying the public that the product contains this material that may harm the public health and environment by reducing ozone in the upper atmosphere. However, since CFC propellants were banned in 1978 by FDA and EPA for all but a few exempted drug inhalers, aerosols using this material represent less than 1 percent of all aerosol products and are being phased out.

Under the Hazardous Substances Act, a broad range of chemicals and other products that have been demonstrated to create particular hazards are required to have prominent and specific cautionary labels—identifying the type of hazard with "signal" words such as DANGER, WARNING, or CAUTION—affixed to the principal display panel of the product container. The regulations specify type sizes and other requirements.

It is also important to note that CPSC, as with other regulatory agencies, has no jurisdiction over products that are covered by other regulatory agencies. For example, CPSC is not responsible for products covered by the federal Insecticide, Fungicide and Rodenticide Act, which is administered by EPA.

Products falling under the PPPA are those of any household substance, including drugs, that require what CPSC dubs "special" or child-resistant packaging to protect children from personal injury resulting from the handling or ingestion of such substances (see Table 20.7) [10]. The criteria for such rulings are derived from continuous study of national hospital records of injuries and deaths. These studies indicate that before the law was enacted, more than 200 children died each year as the result of poisoning due to household chemicals including aspirin and other drugs [11]. Since then,

TABLE 20.7. Products Requiring CR Packaging.

BATHROOM
Antihistamine/sleep aid containing diphenhydramine
Aspirin
Aspirin substitute containing acetaminophen
Cough syrup with codeine (a controlled drug)
Glue and artificial fingernail remover containing acetonitrile
Ibuprofen
Iron-containing medicine
Iron-containing vitamins
Loperamide (an anti-diarrhea medicine)
Mildewcide
Naproxen
Oil of wintergreen (methyl salicylate)
Oral prescription medicine
OTC preparations containing lidocaine and dibucaine (anesthetic medicines)
Permanent hair wave neutralizer containing sodium or potassium bromate
Toilet bowl cleaner
Mouthwash containing 3 grams or more of ethanol (alcohol)
KITCHEN
Ant and roach bait
Drain cleaner containing sodium or potassium hydroxide or sulfuric acid
Furniture polish containing petroleum distillates
Oven cleaner containing sodium or potassium hydroxide
GARAGE OR STORAGE AREA
Antifreeze containing ethylene glycol
Charcoal lighter fluid containing petroleum distillates
Gas line antifreeze containing methyl alcohol
Lawn and garden pesticide
Paint thinner containing petroleum distillates
Pool chemicals
Turpentine
Windshield washer liquid containing methyl alcohol
PENDING RULES
Ammonia
Petroleum distillates

Source: Title 16 of the Code of Federal Regulations (CFR), Chapter 2, Subchapter E, Part 1700. 14.

poisoning deaths have steadily declined, dipping to a low of 31 in 1987 [12]. In 1994, the most recent figures available, 34 deaths were recorded [13].

The decline in deaths is due at least in part to the development of container closures that are designed to frustrate opening by children, but are readily accessible for adults (see Figure 20.3).

Candidate closures were originally each tested by 200 children, used in pairs, between the ages of 42 to 51 months, divided evenly by sex and into

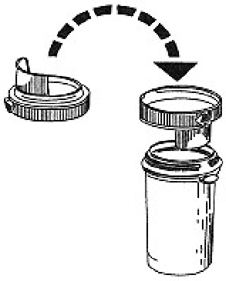

Figure 20.3.
A line-up-the-arrows-to-remove closure with vertical leveraging tab combines CR and elder-friendly features. Dual-purpose design, dubbed Snap-Safe, also offers both CR and non-CR modes.
(Source: Lermer Packaging Corp., Garwood, New Jersey, used with permission.)

ten age groups. The unit packages passed if they resisted child opening (including use of teeth) for 5 minutes or, depending on toxicity, a child failed to open five unit packages in 10 minutes.

Adults were tested, too, for opening capability. Originally, 100 nonhandicapped people (70 percent women between the ages of 18 and 45) had to open the test packages within 5 minutes (up from an original 3 minutes).

The supply of available children was seriously depleted, even after reducing the numbers to 150 children per test, because a child is permitted to take part in only two tests. Also, many parents would not permit their children to participate, believing that the tests simply taught them how to open hazardous containers.

Older citizens, particularly those with handicaps, complained about the difficulty of opening CR closures. As a result, they either left the CR cap off or transferred the drugs to other containers.

In 1983 the CPSC announced its intention of creating new test rules. After a 12-year study and the testing of many different panel arrangements and test procedures, a new protocol was published on July 21, 1995, for implementation July 22, 1996, but was given an 18-month stay of enforcement until January 1998 [14].

In the new protocol, 50 children from 42 to 51 months in age are tested for 10 min, 5 min unaided, then another 5 min after a visual opening demonstration and instructions and the permission to use their teeth. The tests can be continued with succeeding 50-child panels up to a total of 200 children. The closure must defeat 85 percent of the children before the demonstration and 80 percent after.

Adult testing has changed the most. The adult panel now consists of 100 senior adults ranging in age from 50 to 70 years, with 50 percent in the 60- to 70-year category and an even split in the 50 to 54 and 55 to 59 age groups. All groups will contain 70 percent women and 30 percent men. In the test, panelists are given 5 min to open a container and 1 min to close it. It passes if 90 percent of the panel can successfully open and reclose the package in the time allotted.

Further implementation of child safety is embodied in the Child Safety Protection Act of 1995, which requires any manufacturer, retailer, distributor, or importer to report to CPSC within 24 hr any incident in which a child of any age has choked on a small part of a game or toy and required medical treatment, ceased breathing for any length of time, suffered serious injury, or died. Games containing small parts must have a cautionary label and no toy or game may have a part that fits entirely into a test cylinder devised by CPSC and comparable in size to a toilet paper tube (see Figure 20.4) [15].

Even if the part does not fit into the cylinder, it must still be subjected to a random drop test that simulates normal and foreseeable abuse. Any ele-

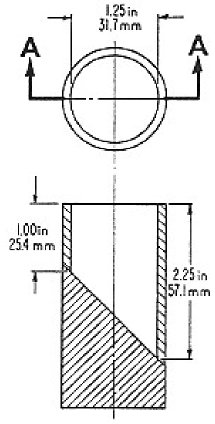

Figure 20.4.
To test for choking hazards, CPSC has developed a small parts test cylinder. It is used to test elements that become detached during a random drop test. If the element fits entirely in the cylinder, the article will be banned. (Source: CFR 16, Chapter II, Section 1501.4.)

TABLE 20.8. Consumer Product Safety Commission (CFR 16, Chapter II, Commercial Practices).

Parts	Regulations
	SUBCHAPTER A—GENERAL
1000–1061	Commission organization, policies, procedures, rule making, advisory committee management, and adjudicative methods
	SUBCHAPTER B—CONSUMER PRODUCT SAFETY ACT REGULATIONS
1101–1406	Substantial product hazard reports, safety standards, bans on unacceptable products, and requirements for performance and technical data on self-pressurized consumer products containing chlorofluorocarbons
	SUBCHAPTER C—FEDERAL HAZARDOUS SUBSTANCES ACT REGULATIONS
1500–1512	Administration and enforcement regulations, method for identifying toys hazardous to children under 3 years of age, electrical toys, fireworks devices, cribs, rattles, pacifiers, and bicycles
	SUBCHAPTER D—FLAMMABLE FABRICS ACT REGULATIONS
1602–1632	Policies and interpretations, investigations, inspections and inquiries, and standards for the flammability of clothing textiles, vinyl plastic film, children's sleepwear, carpets and rugs, and mattresses and pads
	SUBCHAPTER E—POISON PREVENTION PACKAGING ACT REGULATIONS
1700–1702	Poison prevention packaging definitions, statements of policy and interpretation, substances requiring special packaging, testing procedures for special packaging, petitions for exemptions from the Act requirements and the procedures

ment that becomes detached is then placed into the test cylinder. If it fits entirely, the test is failed and the article will be banned. See Table 20.8 for details on the three major laws affecting packaging located in CFR 16, Commercial Practices.

Interstate Commerce Commission

The original purpose for creating the Interstate Commerce Commission (ICC) was to control economic matters relating to transportation, such as mergers, operating authorities, and rates, some of which it still monitors, although day-to-day requirements for freight packaging and rates are basically established by the National Motor Freight Traffic Association, Alexandria, Virginia, in a *National Motor Freight Classification* and by the National Railroad Freight Committee, Atlanta, Georgia, in a *Uniform Freight Classification*—all with the approval of the ICC. New England truck carriers and cargos follow a *Coordinated Freight Classification* tariff.

The three regulatory documents are similar, but differ slightly in tariffs and in requirements. The regulations, derived from old English law regarding the licensing of common carriers, describe and limit services and their conditions of performance; set rates, generally in cents per 100 lb.; and classify all products by such factors as value, density, fragility, potential for damaging other cargo or the carrier's equipment, and the frequency and direction of shipping.

Trucking and Railroad Rules

Rail and trucking rules each establish product classifications that have one or more rules designating the package(s) to be used for safe transport of goods. A carrier can refuse noncompliant packaged goods or accept them for a penalty fee, usually making the shipment ineligible to receive freight damage claims. A process is established where a shipper can petition to run performance test shipments in a new package, the success of which can then result in acceptance by the carriers.

Rules governing shipments are numerous but the most important packaging regulations are Rules 40 and 41 for rail shipments and Items 222 through 222–6 for truck.

To find the correct package(s) for any product for either rail or truck shipment, first look up the product in the alphabetical listing of the appropriate classification. Using the item number shown there, look up the number in the numerical tables which will provide the carload minimum in pounds and the carload rating for rail cars and the class for trucks. In these listings, 100 percent is full tariff. Generally, the listing may specify a numerical standard package and/or may simply define a "box." Specified containers can be looked up by number in the "package description" section (rail) or "specifications for numbered boxes" (truck).

For specified types of containers, structures and tests are listed or can be calculated from descriptions in Rules 40, 50, and 51 (rail) and in Items 110 to 215 and 230 to 297 (truck).

Rule 40 and Item 222 are for corrugated boxes, which must carry a certificate of box manufacture that defines the burst strength, weight of combined facings, the size limit for a box using these combinations, and the maximum gross weight permitted in boxes of any particular construction.

Rule 49 (rail) and Item 689 (trucks) provide information on how to set up and conduct test shipments for new containers or with new loading and bracing techniques.

Today, the edge crush test is preferred over burst strength tests by many and is an acceptable alternative on the certificate. Packages must pass a drop test, which varies with gross weight. It should be noted that these rules are for minimal constructions. Packagers would be wise to test stronger constructions for particularly fragile products or for products to be shipped in particularly demanding environments.

LTL and Rule 180

A high proportion of goods transported by trucks spend at least part of their distribution path in less-than-truckload (LTL) quantities either as mixed containers or in single palletized units. This shipping method is also subject to a great deal of damages.

Creation of performance tests to establish safe packaging standards has long been the goal of distribution engineers, dating back to the 1940s and creation of the National Safe Transit Committee, now the International Safe Transit Association (ISTA), East Lansing, Michigan, and its relatively simple performance tests. These widely used tests then led to creation of a more interpretive standard, D-4169, created in 1982 by a committee of the ASTM (American Society for Testing and Materials), West Conshohocken, Pennsylvania.

The continuing need for similar performance testing of LTL shipments led, some years ago, to formation of a technical committee by the Institute of Packaging Professionals, Herndon, Virginia, that, working in coordination with the ISTA and packaging engineers from the trucking industry, created Rule 180, which was incorporated into the *National Motor Freight Classification* in November 1994.

Rule 180 reveals its ISTA and ASTM parentage, but is also distinctly tailored to meet the needs of the multiple abuses created in the LTL environment and to provide alternative test methods (A, B, and C), which cover both single and palletized shippers and also can be performed by a majority of packager and third-party testing facilities.

The test is two-fold: first demanding a compression and vibration test that represents the road travel environment, followed by an impact test that demonstrates truck loading and unloading sequences and “cross-dock” movement in distribution terminals.

A special set of 14 case markings also were created for LTL shipments (see Figure 20.5) and must be preprinted or applied as labels to packaging for commodities requiring special or additional care in handling or stowing [16]. These markings shouldn't be used unless specifically required as noted in Table 20.9.

The classification of articles for shipment, the various rules, and specified packages are covered in the *National Motor Freight Classification,* currently

Figure 20.5.
In addition to shipping container markings required by CFR, Title 49 for the shipment of hazardous materials, pictorial symbols or precautionary wording must be conspicuously shown only when conditions are applicable, indicating special handling or storage requirements. Palletized or unitized loads may be marked as a single unit. Markings must be shown on two adjacent panels as a minimum, with the exception of markings shown in Secs. 7(a), 8(a), 11, and 13. Symbols may be printed or adhered as a label. For prominence, such symbols may be within a border or have an opposing background color. (Reproduced from the National Motor Freight Classification 100-W by permission of the copyright holder, American Trucking Associations, Inc., Alexandria, Virginia.)

TABLE 20.9. Conditions Requiring Use of Special LTL Markings.

PROTECT FROM:	
Heat	Freezing
Moisture	Magnetics
Stacking	Hand/fork-truck handling
CERTAIN PRODUCTS THAT MUST:	
Remain upright	Stack to a limited height
Face upward	Be handled by hand/fork-trucks
CERTAIN PRODUCTS THAT ARE:	
Fragile	Top heavy
Off-center in balance	

NMF 100-W, but renumbered and brought up to date periodically and sustained between new volumes by periodic supplements. The document is available from the American Trucking Associations; 2200 Mill Road; Alexandria, VA 22314-4677.

Classification of goods and required packages used for rail transport are covered in the *Uniform Freight Classification,* currently number 6000K, which also is updated periodically with interim mailings of supplements The document is available from the Chairman; National Railroad Committee; 151 Ellis St. NE, Suite 200; Atlanta, GA 30335.

Air Transport Regulations

Air transport of standard goods is governed in the United States by the Air Transport Association of America, Washington, D.C., and for international flights by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA), both based in Montreal, all of which only suggest packaging procedures for ordinary products.

Post Office and Private Carriers

Parcel post regulations are to be found in the Postal Service Manual available for examination at all post offices.

Private carriers, such as United Parcel Service, Atlanta, and Federal Express Corp., Memphis, Tennessee, have their own manuals regulating the size and structure of packages and some types of product limitations in mixed cargoes. These organizations should be contacted to determine exact packaging specifications and size and weight limitations.

Hazardous Goods (DOT)

Originally, regulation of the transport of hazardous materials was under the command of the ICC. However, as U.S. traffic of all kinds soared, it became obvious that a larger organization was needed to keep up with technical developments and regulatory activities in all branches of transportation, particularly for packagers in the packaging and transport of hazardous materials. This was accomplished in 1967 by establishment of the DOT, a huge federal agency, which has responsibility for every form of interstate transport. Its Research and Special Programs Administration governs the packaging and transport of hazardous materials in interstate shipments. It classifies hazardous materials, determines if and how much of such a product can be shipped in each form of transportation, and provides guidance in the development of packaging for hazardous products.

DOT standards for the transport of explosives, corrosives, flammables, poisons, oxidizers, irritants, radioactive materials, etiologic (infectious) agents, and miscellaneous hazardous materials and mixtures of materials are contained in a Hazardous Materials Table in CFR 49, Transportation, which lists the hazard class, packaging group, required labels, special provisions and exceptions, and quantity limitations in individual packages. This table still exists with the addition of UN numbers for each hazardous material or an NA number if a material does not have a satisfactory shipping name and, therefore, must be restricted to U.S. and Canadian distribution.

Originally, the packager then looked up the various specification containers approved for each material and selected one that fit each of the requirements for the specific material and distribution method. The system was effective, but limited use of advanced technology, even though there was always the possibility of getting a variance from DOT for a technologically superior nonspecification container. Small packagers, in particular, were hampered by the cost of the standardized containers.

Consideration of a performance-oriented standard began in the United States years ago and was actually put into practice in the mid-1980s by some European and third-world countries and the International Maritime Organization (IMO), London, which governs transport of hazardous goods by sea beyond continental boundaries. This led quickly to the publication by the United Nations of *Recommendations on the Transport of Dangerous Goods* and intensified work in the United States that resulted in the Hazardous Materials Transportation Uniform Safety Act of 1990, issued as a final rule at the end of 1991 and implemented over a 5-year span. Most of the basic differences between the U.S. and UN plans have been worked out and coordinated, as for example, the types of cautionary labels used on packaging to denote the hazard (see Figure 20.6 for a sampling of these identifications). The

Figure 20.6.
For international shipments of hazardous materials, cautionary labels should follow UN requirements. Some examples of the labels required are shown above. The number designation and background color is part of each design. No. 1 (explosive), for example, has an orange background; Nos. 2.1 (flammable gas) and 3 (flammable liquid) are red with the flame in white or black; No. 4.3 (flammable gas when exposed to water) is blue with the flame in white or black; No. 5.1 (oxidizer) is yellow; No. 6 (toxic) and No. 7A (radioactive) are white; No. 8 (corrosive) is half white and half black; and No. 9 (miscellaneous dangerous substance) features black stripes on a white background. (From Recommendations on the Transport of Dangerous Goods, Ninth Revised Edition, 1995. Reprinted with permission of the United Nations.)

UN recommendations are used for international shipments, but DOT's closely conforming specifications are also acceptable for most international shipments.

The DOT definition of packaging ranges from small non-bulk containers to intermediate and large-bulk packages, which include portable tanks and railcars all of which can be one-trip or returnable in usage if they conform to design specifications.

Today, UN-standard packages manufactured outside the United States can be used here if they fully conform to UN standards and if reciprocal treatment is granted by the country in question to domestically manufactured UN-standard and DOT-specification containers. All containers and the materials from which they are made must pass exacting physical and environmental tests and the containers must carry the identity and address of the manufacturer.

Creation of new performance packages for hazardous products is allowed under the modern regulations, but they must conform to specifications set forth for each packaging class that—in varying degrees of detail—specify required structural features, materials, fabrication methods, and methods of testing both materials and final containers. The tests must be run by a certified laboratory, which can either be the packager or an independent laboratory. However, a packager would need to be creating new performance packages on an almost continuous basis to afford the rather expensive facilities now required. Hence, the growth of many independent testing facilities.

For more details on the somewhat intricate workings of CFR 49, Transportation, see Table 20.10.

Hazardous Goods by Air

For air transport of dangerous materials, regulations are imposed by ICAO and IATA in agreement with DOT and are somewhat more severe. These organizations have strict rules and even some prohibitions on the carrying of individual hazardous chemicals and the amount permitted on passenger and cargo aircraft. For details, there are the *Dangerous Goods Regulations* from IATA and the *Technical Instructions for the Safe Transport of Dangerous Goods by Air* from ICAO. Both documents are obtainable from IATA; 2000 Peel Street; Montreal, Quebec H3A 2R4 Canada.

Some private carriers also handle hazardous materials and are, in general, more strict in their requirements than DOT. United Parcel Service has a detailed manual, *Guide for Shipping Ground and Air Hazardous Materials*. Federal Express prefers to have shippers contact its hazardous materials specialists to work out the details. Some states, but not all, also have hazardous materials regulations to govern in-state shipments. In addition, local agencies such as road and tunnel authorities and fire departments often have restrictions as well.

Hazardous Goods by Water

In the coastal and inland waters of the United States, the transport of hazardous goods is supervised by the Coast Guard, which is a division of the DOT. The regulations list two tables of solid materials capable of bulk carriage and make a provision for carrying other chemicals with the approval of the Coast Guard Commandant. Likewise, regulations are specified for the carriage of bulk liquids and liquified gases in barges or ships with tabular specifications for the products and their stowage. Details on the testing and approval of shipping containers generally used to hold such cargo are contained in CFR 46, Shipping, Subchapter B, Part 450.

The carrying of hazardous materials in international waters is exhaustively detailed in the *International Maritime Dangerous Goods Code,* a five-

TABLE 20. 10. Key Regulations to Packaging Hazardous Goods

(CFR 49, Transportation, Chapter 1).

Parts	Regulations
	SUBCHAPTER C
171	General information, regulations, and definitions
172	Hazardous materials table
173	Shippers—general requirements for shipments and packagings
174	By rail
175	By aircraft
176	By vessel
177	By public highway
178	Specifications for packagings
179	Specifications for tank cars
180	Continuing qualification and maintenance of packagings
Chapter IV, Department of Transportation, Coast Guard	
	SUBCHAPTER B
450	Safety approval of cargo containers, general provisions
451	Testing and approval of containers
452	Examination of containers
453	Control and enforcement of container rules
United Nations Recommendations on the Transport of Dangerous Goods	
CHAPTER	REGULATIONS
1	Scope of the recommendations
2	List of dangerous goods most commonly carried
3	Special provisions relating to individual substances and articles
4	Special recommendations relating to Class 1 (explosives)
5	Special recommendations relating to Class 3 (flammable liquids)
6	Special recommendations relating to Class 6 (poisons)
7	Special recommendations relating to Class 7 (radioactives)
8	Special recommendations relating to Class 8 (corrosives)
9	General recommendations on packing
10	Special recommendtions on packing for Class 1 (explosives)
11	Special recommendations relating to Class 5 (oxidizers)
12	Recommendations on mutimodal tank transport
13	Recommendations on consignment procedures
14	Special recommendations relating to Class 4 (flammable solids)
15	Special recommendations for dangerous goods in limited quantities
16	Recommendations on intermediate bulk containers (IBCs)
17	Multimodal tank containers for refrigerated liquefied gases

volume compendium published by the IMO, which also follows the UN-suggested recommendations. As with air transport, the regulations specify shipboard location of hazardous materials in cargo and passenger ships and location with respect to living quarters in all ships and by amounts for the various classes of hazardous materials. Volume I also contains the complete alphabetical listing of hazardous materials, their codes, classes, and packaging groups. Volume V (supplement) is devoted to emergency procedures, first aid, and reporting procedures. Volumes II through IV contain complete instructions on the packaging and placarding of the IMO's nine classes of hazardous chemicals and their stowage requirements (see Table 20.11). For

TABLE 20. 11. Important Aspects of the International Maritime Dangerous Goods Code.

VOLUME	CONTENTS
I	General code introduction
	Packing recommendations
	General alphabetical index of dangerous goods
	Numerical index
	List of definitions
II	Class 1: Explosives
	Class 2: Gases (compressed, liquified, or dissolved under pressure
	Class 3: Flammable liquids
III	Class 4: Flammable solids
	Class 4.1: Flammable solids
	Class 4.2: Substances liable to spontaneous combustion
	Class 4.3: Substances which, in contact with water, emit flammable gases
	Class 5: Oxidizing substances and organic peroxides
	Class 5.1: Oxidizing substances (agents)
	Class 5.2: Organic peroxides
IV	Class 6: Poisonous (toxic) and infectious substnces
	Class 6.1: Poisonous substances
	Class 6.2: Infectious substances
	Class 7: Radioactive materials
	Class 8: Corrosives
	Class 9: Miscellaneous dangerous substances and articles
Supplement	
	Emergency procedures
	Medical first aid
	Solid chemicals in bulk
	Reporting procedures
	Packing cargo transport units
	Use of pesticides in ships

details, the *International Maritime Dangerous Goods Code,* is available from the International Maritime Organization; 4 Albert Embankment; London SE1 7SR, United Kingdom.

EPA and FIFRA

As pointed out previously, federal control of shipments for FIFRA insecticides, fungicides, and rodenticides, at one time the province of FDA, has been transferred to the EPA. Such substances are subject to CR closures if they are or could be distributed in the home environment and are toxic and/or corrosive [17].

Size of the container is also a criterion. Large sizes are generally excepted as are pesticides applied by a certified applicator [18]. However, a producer of pesticides may elect to use CR packaging even though it is not required by the scope of the regulations.

Government Packaging

Federal and Military Specifications and Standards govern all purchasing for the government, by far the largest single customer in the country. The documentation is voluminous and the packaging is divided into three classes or levels that are used by both federal and military establishments.

Level A consists of strapped solid fibre boxes, often wax coated for long-term storage and severe environmental conditions. The procedures and inspection of products and packages at this level are very detailed and time consuming and normally are practical only for general products shipped to the military in times of conflict and for sensitive and fragile equipment.

In contrast, Level B uses regular slotted corrugated containers and domestic shipping conditions. To save money, in times of peace, a great deal of the appropriate military material is packaged at Level B or Level C. The latter uses the lowest cost packaging or no packaging at all, consistent with safe handling and acceptance by the carriers.

Any packager that bids on a contract for federal or military packaging should have the applicable specifications and standards in hand. To find out what is required, the Department of Defense publishes two indexes, Part 1 an alphabetical listing and Part 2 a numerical listing, both of which are necessary to find the requisite subjects and the index numbers by which they are characterized. The publications are available from U.S. Naval Publications; 5801 Tabor Ave.; Philadelphia, PA 19120.

Some of these standards and specifications are useful as sources of technical information and test methods for civilian packagers, too. For example, MIL-STD-105D is the generally accepted reference for quality control sampling and inspection. PPP-F-320 gives detailed construction requirements for corrugated board. PPP-G-460 covers glass containers. UU-P-31 includes paper specifications and test methods that are identical with standards from ASTM and the Technical Association of the Pulp and Paper Industry (TAPPI), Atlanta. PPP-B-621 is a good design guide for wood boxes.

Other Laws and Regulations

There are many laws that do not affect packaging directly, but still have a very strong indirect influence on how it operates from both materials and machinery standpoints.

The list could go on forever, but one of those closest to home are the container, labeling, and advertising regulations of CFR 27, Alcohol, Tobacco Products, and Firearms. People working with these products should closely study the applicable sections.

Similar in interest to all packagers are sections of the environmental safety and machine safety sections enforced by OSHA. Since these are general regulations, not specifically targeting packaging operations, their interpretation as it applies to packaging can only be determined by a close study of the applicable parts of CFR 29, Labor and an OSHA Technical Manual released in 1995 that details, among many things, safety regulations governing materials handling, engineering controls, the use of robotic devices, inspection, storage, and maintenance in the work place, all of which are applicable to the packaging operation. As with all federal publications, this OSHA manual is available from the U.S. Government Printing Office; Superintendent of Documents; Washington, D.C. 20402.

Patents, Trademarks, and Copyrights

Patents

On April 10, 1790, President George Washington signed into law the Patents Act. For the first time in history an invention became a form of property, and an inventor had the right to exercise exclusive control over commercial use of it for a fixed period of time. Patents had been granted previously by acts of the state legislatures, but there were no federal laws, and patents were difficult to obtain. The practice of numbering patents was started in 1836 with the establishment of the modern patent office. Design patents were first granted in 1842, and plant patents in 1930.

More than 5.5 million patents have been granted in the United States, plus about 400,000 design patents and more than 300 plant patents [19].

There is an important difference between a patent and a trademark. The issurance of a patent gives a high degree of protection immediately, without prior use or publicity. A trademark, on the other hand, must be in commercial use when it is registered. The act of registering gives constructive notice to all later users of the mark. Any person who has invented a process, machine, article of manufacture, composition of matter, ornamental design, or new variety of plant, which meets certain requirements, may obtain a patent. The filing fee varies from $160 to $770, depending on the type of applicant and patent [20]. Other charges and attorney's fees could raise the cost to more than $5,000 [21].

A patent is granted for 20 years (14 years for design patents) and cannot be extended except under very limited circumstances [22]. What is granted is not the right to make, use, or sell the invention, but rather the right to exclude others from making, using, or selling it [23]. An article no longer is required by law to be marked “patented,” but before there can be a recovery of damages for infringement, it is necessary to serve notice of the existence of the patent. Marking the patent number on the item serves as a form of notice to the public at large. The use of “patent applied for” or “patent pending” has little value in a legal sense, but it may be a deterrent to anyone who might want to copy an invention.

It is more difficult to define *invention* than to list some of the things that are not considered patentable. Algorithms, laws of nature, physical phenomena, abstract ideas, and new plants found in the wild are not patentable. However, a new combination of old elements may be patentable, particularly if it solves a long-felt need as demonstrated by prompt and general adoption by the public.

To be patentable, an invention must be new, useful, and nonobvious. While an inventor is not required to have actually made his invention, it must be fully described in the application. The first step, after deciding to file for a patent, is to establish the date of invention. In this country at the present time, the date of invention is more important than the date of filing because in the case of “competing” applications, the first to invent will be awarded the patent.

A complete patent application includes a written description with at least one claim, preferably with drawings, an oath or declaration signed and dated by the inventor (s), and a filing fee [24]. A search of patents already issued should be made to see whether the invention has already been patented. This is usually done by an expert in the field, who should be supplied with an accurate description of the invention and given a limit on the time or money to be expended. There is no guarantee that every pertinent patent will be found, but a group of patent papers will be furnished that are close to the subject. This will help to determine whether it is worthwhile to file an application for a patent.

A patent search also may be of benefit by showing how the claims can be made more definitive and perhaps stronger. It is sometimes desirable to have a search made for other reasons. When no invention is involved, but the solution to a problem is being sought, it is often helpful to have a “state-of-the-art” search made. This will reveal the many approaches to the problem that have been made by inventors and may suggest an answer that had not been previously considered.

Another reason for making a patent search is to determine the validity of an existing patent. If a manufacturer has infringed or intends to infringe an issued patent, he may want to determine the likelihood of its being upheld in a court of law. This kind of search can be very expensive, since it attempts to find prior conception through publication in domestic or foreign patents or even in technical journals. Any description of the invention that predates the filing of the patent in question by more than one year may be sufficient to invalidate it.

A patent consists of two main parts, the specification and the claims. The “specification” is for the purpose of teaching the reader how to make and use the invention, and it often has drawings to clarify the description. This makes the “claims,” which are the heart of the patent, more understandable. Some of the claims should be as broad as possible, and others will need to be more specific.

The contents of the application, including the serial number and the filing date, are kept confidential by the Patent Office until the patent is granted, unless there is interference due to two applications having similar claims being filed at the same time.

The Patent Office examiner will read the application when it reaches the top of the pile—perhaps several months or longer after filing. He or she will search the patent files and the literature to see whether the features claimed in the application have been published before. The examiner, in a letter called an “office action,” may then reject certain of the claims and cite the references that support his/her opinion. Nearly all applications are rejected after the initial filing.

The office action must be answered within six months by a letter called an “amendment” or “response,” either arguing that the examiner's rejection is unfounded, or asking the examiner to cancel or reword the claims in question. The amendment must be a bona fide attempt to advance the case, and not for the purpose of postponing the granting of the patent.

This exchange of actions and amendments may be repeated several times until the patent application is accepted or the examiner states that the rejection is final. An appeal can be made to the Board of Patent Appeals if desired. The whole process takes an average of 2.5 years.

A patent application must be filed within one year after the invention is made public, either by being described in a printed publication, being used in public, or being offered for sale. Otherwise the inventor loses his rights to a patent. The *Official Gazette,* published weekly by the Patent Office, contains a claim and a representative drawing from each patent granted during that week with other news and information pertaining to patents. An annual index gives the names of patentees in alphabetical order and a list of patents by subject.

Trademarks

The Trademark Act of 1905 authorized the registration of trademarks used in interstate commerce. Previous laws applied only to trademarks in commerce with foreign nations. The Lanham Act of 1946 updated the original law, making the following important changes: provisions for registering service marks and certification marks; incontestability of trademark registrations under certain conditions; and cancellation of registrations after the sixth year if an affidavit of use is not filed during that time.

The principal function of a trademark is to indicate the origin of goods or services. It says, in effect, that the goods or services originate with a particular manufacturer or service provider. Secondary purposes are as an indicator of the quality of the goods or services and to create and maintain a demand for the product. Unlike a patent, the act of registering a trademark does not establish any rights to the mark. It does, however, help to strengthen the rights, which are established through commercial use of the trademark. The only way that ownership of a particular mark can be established is through wide use of it on a continuing basis. The more it is used in public, the stronger it becomes. If the use is discontinued, the rights to the mark may be lost.

The fee for registering a trademark is $245 [25]. The registration will remain in effect for 10 years with unlimited renewals permitted for additional periods of 10 years [26]. The mark is published in the *Official Gazette* of the Patent Office at the time of application or renewal. The *Official Gazette,* published weekly, also has an annual index.

Any word, name, symbol, device, or combination thereof that is used by a manufacturer or merchant to distinguish his goods or services from those manufactured or sold by others can be considered a trademark. A word or phrase that is descriptive of a product is not nearly as strong as a fanciful trademark. A person's name does not make a good trademark, since any persons with the same name would have some rights to that name as a trademark, and it would be difficult to stop them from using it. A geographical or other location name is also difficult to protect.

It is helpful to use the word *trademark,* the initials T.M. or the symbol in conjunction with the name or symbol, to serve notice of the claim for exclusive use. If this is used broadly enough, without protest from other manufacturers, it strengthens the rights of the user. It is not necessary to use

T.M. with the mark every time it is used. Once is enough on each package component, if it is in a prominent place. It is also useful to use the word "brand" after the trademark to strengthen it.

There is a risk that a trademark may become a generic term for a group or class of products. This has happened with such well-known words as thermos, mimeograph, escalator, cellophane, and aspirin in the United States. To prevent this, it is best to use the name only as an adjective, not as a noun, and always to capitalize it.

Copyrights

To protect the "right to copy" for the author of literary, musical, artistic, or dramatic works, it is necessary to fix the work in a tangible medium of expression and file a registration as described below.

In general, a work is protected under copyright for the author's lifetime, plus an additional 50 years, according to the 1976 copyright law. If the work is anonymous, the duration of the copyright is 75 years from publication or 100 years from creation, whichever is shorter.

An idea cannot be copyrighted, only the expression of the idea can be copyrighted. Original factual compilations and figures and charts constructed from published material but in a different way may be copyrightable. A certain amount of fair use can be made of material that is in the public domain. Fair use allows copying without permission if the use is reasonable and not harmful to the copyright owner. However, to be on the safe side, permission from the copyright holder or publisher should be obtained before reproducing a photograph, illustration, figure, table, or block of text.

In order to file a registration with the Copyright Office, the applicant must send two copies of the best edition of the work as published with a filing fee and an application form. The filing fee for a document with a single title is a basic $20 [27]. Application forms and information can be obtained from the U.S. Copyright Office; Library of Congress; Washington, D.C. 20559.

The many details involved in patenting, trademarking, and copyrighting are presented in CFR 37, Patents, Trademarks, and Copyrights, available from the U.S. Government Printing Office; Superintendent of Documents; Washington, D.C. 20402.

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Chapter 21— Packaging and the Environment

History

Ever since humans first gathered together to form cities, the accumulation and disposal of solid waste has been a touchy subject, but never more so than in modern urban society—starting in the United States, flourishing in Europe, and gathering momentum in Asia.

The elements most in disfavor have always been packaging, although the discarded wrappings of goods are less than half the total for municipal solid waste in the United States (see Table 21.1) [1]. The problem is that, to the citizen, packaging is a most visible waste and one that requires constant clean-up effort and cost both in curbside collection and along the highways and byways where less careful citizens strew it.

Mutterings about urban waste became focused after World War II with the great growth of consumer unit packaging needed to enclose the torrent of prepared foods and other new household products. The popularity of fastfood outlets, which shifted many eating occasions outside the home, further increased both trash-collection volume and roadside litter. In addition to consumer waste, industrial packaging, which ranges from motor oil containers and automotive parts cartons to bulk containers for raw materials and subassembly carriers for manufacturing operations, also increased the strain on local collection and disposal resources.

However, the first modern consumer uprising about packaging, during what might be dubbed the first environmental era of the mid-1960s and early 1970s, did not start as a matter of solid-waste disposal or littering, but as a dispute between paperboard and plastic containers for meats and fresh produce. Consumer advocates claimed the public was being cheated by retailers who concealed bad or inedible parts of these foods in opaque paper-

TABLE 21.1. 1994 U.S. Packaging Solid Waste.

Material	Tons (million)	Percent of MSW	Recovered Tons (million)	Recovered Percent of Total
Glass	12.1	5.8	3.1	6.3
Steel	3.1	1.5	1.6	3.2
Aluminum	2.1	1.0	1.2	2.3
Corrugated	28.4	13.6	15.7	31.9
Paper/Paperboard	9.4	4.5	1.4	2.8
Plastics	9.5	4.5	0.7	1.4
Wood	10.2	4.9	1.4	2.9
Misc.	0.2	0.1	-	-
TOTAL	75.0	35.9	25.1	50.8

Note: Total MSW generated in the United States was approximately 209 million tons (189.6 million metric tons) in 1994, the latest figures available from the Environmental Protection Agency. Of this, 49.3 million tons (44.7 million metric tons) was recovered via recycling or composting.

Source: Reprinted from *Characterization of Municipal Solid Waste in the United States: 1995 Update,* Environmental Protection Agency, Washington, D.C.

board trays, which prevented a view of product undersides. They called for total clarity as provided by plastic trays and wraps (an ironic twist in view of subsequent consumer attitudes about plastic packaging).

The fight was bitter and fought mainly in the Northeastern states by vendors, publicists, and lawyers from the paper and plastic industries. Both sides claimed economics. Paper people claimed easier disposability. Plastics suppliers claimed both visibility and greater cleanliness since trays did not soak up food juices.

When both sides had thoroughly discredited each other and alienated the public, the main point that stuck with community leaders was disposability from the standpoint of both solid waste and littering. In those days, and still today in some cases, aging incinerators had difficulty attaining complete combustion of some plastics, and paperboard advocates made much of the release of fumes from the burning of these materials.

New York City took the first lead with a plan to tax packaging materials based on their “index of disposability.” The law was declared unconstitutional and discriminatory in court, as have all similar measures in the years since. But the environmental fire was lit and has yet to be extinguished.

Gradually, the emphasis switched to one-way bottles and cans for beverages, which posed both solid-waste and littering problems. Enthusiasm spread rapidly, and between 1969 and 1976 more than 1,200 measures were introduced. Just about every state in the union considered a deposit, ban, tax, and/or restriction on the distribution of one-way containers. Currently, ten states have "bottle bills" in force that require deposit/refund fees to encourage recycling and reduce litter.

Another current approach is a litter tax on beer and soft-drink containers. Still other states, prohibit the disposal of recyclable containers, and several ban nondegradable plastic multipack holders because of their lethal effect on some wildlife.

Most extensive was a Minnesota regulation, which would rate all packaging for soaps, foods, beverages, and cosmetics that created a disposal problem or was inconsistent with the state's environmental policies. Packaging with unacceptable scores would be banned from distribution within the state. After a brief trial period, the regulation was declared unworkable and quietly dropped. (However, a similar, somewhat more practical Minnesota law was enacted during the most recent environmental period and is slowly being tested.)

During the first environmental period of the late 1960s/early 1970s, some real progress was made by vendor organizations and knowledgeable state and community agencies in gathering data on the broad issues of littering and solid-waste disposal of packaging. Keep America Beautiful, Stamford, Connecticut, an organization started by a coalition of packaging manufacturers, created a protocol to train people in hundreds of communities not to litter. It is still very successful and set the basis for consumer participation as a first phase in package collection.

Research in the United States and abroad indicated that recycling of packaging waste might be a better long-term goal than incineration or landfill disposal because it would conserve resources, some of which are definitely finite in availability. The paper industry modified plants to accept various types and grades of waste paper and board and developed a greatly expanded capacity for paper and paperboard with recycled fiber content. Vendors also founded a National Center for Resource Recovery, which lasted a few years and sponsored research in collection, sortation, and recycling methods. Packaging suppliers also funded the building of about 50 community pilot programs—including six full-scale urban recycling centers—for the recovery of valuable packaging constituents.

The federal government, which had disavowed responsibility for solid-waste management, regarding it as a local problem, finally passed the Solid Waste Disposal Act of 1965 and the Resource Recovery Act of 1970. These programs would fund local pilot projects for materials recovery.

In the meantime, research and experiments appeared to prove that recycling should be conducted on a large-scale regional basis to enable relatively small volumes of discarded packaging materials to be recovered in sufficient quantities to create markets. Also noted was that local conditions must play a significant role. The amount of waste generated in the mountain states, for example, is much lower than in the more heavily populated mid-Atlantic states. Transportation distances and the location and density of packaging manufacturing facilities also were determined to be critical factors for economic recycling. Since some areas of the country are too distant and/or unpopulated to make recycling feasible and some materials cannot be collected in sufficient quantities, it was recognized there would always be a need for some landfill facilities and more-modern incinerators. Nevertheless, recycling systems were designed and potentials pinpointed.

But when these were revealed to state governors, they simply said they would never be able to come up with the extensive funds required to build and staff such centralized collection and transportation facilities. The severe recession and oil shortage, which occurred in 1974, switched public and governmental attention to more serious and immediate problems, and the developing resource-recovery effort was abandoned and all but forgotten by the general public for a decade, ending the first environmental era.

The Current Situation

Although a few industries and organizations, which adopted environmental packaging measures during the 1960s and 1970s continued to develop technology and applications, widespread environmental consciousness was reborn only in the late 1980s and extends to the present in what might be considered the second environmental era.

A good reason to reestablish this effort is a report by the independent Paris-based Organization for Economic Cooperation and Development, which studied the generation of wastes in a 25-year period from 1970 to 1995.

It declared that the United States generated more municipal solid waste (MSW) per capita than any other developed country in the world and that U.S. efforts to reduce this waste are insufficient. According to Environmental Protection Agency statistics for 1994 (the most recent year available), each American generates 4.4 lb (2 kg) of MSW per day [2]. Of the total 209 million tons (189.6 million metric tons) of waste produced per year, about 24 percent is recycled or composted, 61 percent is landfilled, and 15 percent is burned (usually with energy recovery) [3].

The initial reason for a return to environmentalism in the 1980s, however, was for a singularly different purpose.

The resurgence started in 1988 with a widespread attempt by various states to ban or heavily tax certain forms of plastic packaging, which emerged from the national consciousness as environmentally unfriendly.

Suffolk County on Long Island in New York State passed a law forbidding plastic packaging for foods (later ruled unconstitutional). Connecticut weighed legislation to charge a nickel per package for every nonreusable package sold in the state. Recyclable containers would be charged only 2.5 cents each. Maine banned aseptic drinks in composite-material cartons (since rescinded). Ballot proposals in Oregon and Massachusetts sponsored by Public Interest Research Groups didn't quite make it in 1988 referendums, but would have required reusable or 50 percent-recycled-material containers or a state ban on non-environmentally-acceptable materials, respectively.

California, Connecticut, Florida, Massachusetts, New Jersey, New York, Oregon, and Wisconsin, out of 26 states regarded as “legislative hot spots,” were quite advanced at this point in considering taxes or other restrictions on plastic packaging.

Clearly, if effective, modern packaging—developed over a half-century of technological effort—was to be retained, industry would have to quickly develop meaningful solutions to the growing volume and disposal cost of MSW. In the East, landfills were filling up and closing. New sites everywhere were running into the problem of “not in my back yard” and the cries by environmentalists against waste of natural, sometimes scarce resources became insistent.

The packaging field did respond along with some clear-headed groups of legislators and environmentalists. Unlike Europe, management of solid waste in the United States has been entirely at the state and local levels. Solutions that were rather quickly defined as practical were recycling and source reduction, with a possible alternative in development of environmentally degradable packaging. Individual suppliers and trade associations have done most of the research, development, and the education of state personnel in practical techniques for recovering post-consumer and postmanufacturing waste.

Advance disposal fees, used in countries like Germany with a “producer pays” philosophy to “tax” the manufacturer to cover the cost of disposal or recovery, have rarely been legislated in the United States. The leading example, Florida, adopted and then dropped such a law within 2 years. Hawaii has a disposal fee on glass packaging imports.

Again, unlike some foreign countries, the United States has no national solid-waste reduction program, although some states and local communities have set their own standards. However, there is a national MSW recycling goal of 35 percent by 2005. It was set by the Environmental Protection Agency (EPA) after its original 25 percent goal was met on schedule in 1995. In addition, various trade associations have set recycling goals for their particular materials.

Various preexisting and more recently formed industry organizations address specific issues. Notable are The National Association for Plastic Container Recovery (NAPCOR), Charlotte, North Carolina; The Aluminum Association, Washington, D.C.; American Forest and Paper Association (AFPA), Washington, D.C.; the Can Manufacturers Institute, Washington, D.C.; The Plastics Recycling Foundation, Kennett Square, Pennsylvania; The Society of the Plastics Industry (SPI), Washington, D.C.; The National Soft Drink Association, Washington, D.C.; The Council on Packaging in the Environment (COPE), disbanded in 1997; the Center for Plastics Recycling Research (CPRR), closed in 1996; and the Coalition of Northeastern Governors (CONEG), Washington, D.C.

An organization formed in 1976 to deal with economic issues of interest to the nine Northeastern states, CONEG established a source-reduction program in 1989 that was pronounced as having accomplished its mission of reducing the amount of packaging in the waste stream and disbanded at the end of 1996.

During its 7-year life span, the source-reduction program developed several influential measures. Its model state legislation for the elimination of toxic materials in packaging has been adopted by 18 states. It focuses on heavy metals (lead, cadmium, mercury, and hexavalent chromium) commonly used in adhesives, inks, and colorants.

Another effort, CONEG's Preferred Packaging Guidelines encouraged companies to eliminate and/or reduce (minimize) packaging and use returnable/refillable and/or recyclable/recycled-content designs. In conjunction with the Guidelines, fifty packagers accepted CONEG's Governors' Challenge to Industry that, in the 5-year period ending in 1994, reduced, reused, or recycled 32-billion lb (14.5 billion kg) of packaging at a savings of more than $400 million.

Recycling of Packaging

Although recycling programs have emphasized plastic packaging because of public concern, all types of packaging materials have been involved in the trend to reuse and recycle with some efforts dating back to the 1960s and 1970s or even before.

The general public now accepts the fact that MSW contains all types of packaging waste, and about 20 percent of adults rate the issue as extremely serious, 79 percent have taken some action to help the environment, and 63 percent are personally doing more today to assist in environmental matters, according to a final COPE study before the group disbanded early in 1997 [4].

Plastics

The plastic packaging industry responded to the 1980s threat to packaging by creating the Council for Solid Waste Solutions (CSWS), which would later broaden in scope and become the American Plastics Council (APC), Washington, D.C. Supported by nine major plastics producers, which pledged a start-up fund of $8 million, CSWS launched a campaign in the legislative hot spots to publicize facts about plastic packaging and its capability for recycling, reuse, and incineration for power production.

CSWS asked legislators what they would use instead of plastics if this packaging form was banned and pointed out the utility and economy of existing plastic packaging forms. They also noted that plastic packaging represents a rather small percentage of MSW. Even more than 5 years later in 1994, plastics accounted for only 4.5 percent of MSW generated and only 12.6 percent of packaging waste overall (see Table 21.1) [5].

The industry group also touted recycling and various members started pilot programs to demonstrate its feasibility, particularly with plastic bottles, cushioning, fast-food containers, stretch-film wraps, and bags. With technical efforts directed toward collection, sortation, and development of potential markets, CSWS worked with communities to develop curb-side pick-up programs and centralized collection centers. Early on, plans were made to increase the recycling rate of polyethylene terephthalate (PET) soft drink bottles from 20 to 50 percent by the mid-1990s. That number has yet to be achieved. According to the APC, although volume increased, the PET bottle recycling rate actually fell a bit in 1995 to 32 percent due to rapidly expanding usage of single-serving sizes. In fact, a report from NAPCOR estimated the amount of PET containers recycled in 1995 rose from 565 million lb (256 million kg) to 622 million lb (282 million kg) [6].

Also active was the CPRR at Rutgers University, New Brunswick, New Jersey. Funded by the National Science Foundation (NSF), Washington, D.C., the New Jersey Commission on Science and Technology, Trenton, New Jersey, and the soft drink and plastics industries, it developed commercial methods for the sortation and processing of PET and later the recovery of commingled plastics from MSW. This program shut down in 1996 for lack of funding, but some of its functions continue at Rutgers' Plastics and Composites Group in the Department of Civil and Environmental Engineering, which is developing technology to expand the recycling of commingled plastics into plastic railroad ties.

The trade associations have been active in solving specific problems. For example, one plastic bottle looks very much like another, and successful recycling usually depends on keeping like with like. SPI quickly responded to this problem with development of a coding system for resins used in rigid containers. The code symbols (see Figure 21.1) are located on container bot-

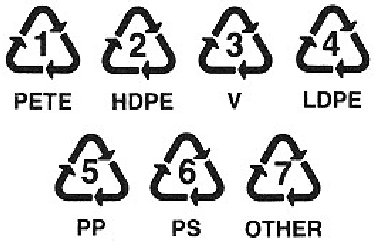

Figure 21.1.
SPI's resin coding system uses seven code numbers and resin abbreviations to identify common bottle and container resins. PETE instead of the more common PET is used for polyethylene terephthalate to avoid confusion with PET Inc., St. Louis. The other code designations include 2 for high-density polyethylene, 3 for vinyl, 4 for low-density polyethylene, 5 for polypropylene, 6 for polystyrene, and 7 for other resins or mixed structures. Codes are sized according to container volume: 0.5 in. (1.3 cm) for bottles ranging from 8 to 32 fl oz (236 to 946 ml); 0.75 in. (1.9 cm) for bottles from 32 fl oz to a gal (0.95 to 3.8 L); and 1 in. (2.5 cm) for bottles larger than a gallon (3.8 L). (Source: Society of the Plastics Industry, Washington, D.C., used with permission.)

toms and a three-year phase-in was established to allow for re-engraving of the enormous number of bottle molds involved. Although developed as a voluntary system, 39 states currently mandate its use, and the net effect is that the codes are a necessity on any bottled product marketed nationally.

Individual suppliers as well as trade associations have started the recycling of mixed film wraps and bags, deposited in supermarket containers by consumers. Industrial collection and return of stretch and shrink packaging has been sponsored by resin and film producers. In fact, industry sources estimate that flexible packaging accounts for just over 10 percent of the plastic packaging being recycled.

A major source of recycled material is the trim waste from thermoforming or bottle-making operations, which is most often ground and directly reextruded into new sheet or containers. This pre-consumer waste is even preferred in many instances since it is less likely to be contaminated than the same type of plastic from MSW. However, it should be noted that some people do not classify use of pre-consumer waste as recycling.

Packagers and consumers also must realize that there are many instances where plastic containers cannot be recycled to produce new ones. Thus, other markets for the recycled resin must be developed. This is an ongoing process, but already the result has been creation of a new industry based on recycled plastics. An example is seen in Table 21.2, which shows major uses, other than bottles, that have opened up for recycled PET flake. Other plas-

TABLE 21.2. Markets for Bottle Flake Derived from Recycled PET Bottles.

Fiber for Carpet Yarn, Industrial Fabrics, and Clothing
Extruded Film and Sheet
Injection Molding
Strapping Filament
Reinforced Thermosetting Plastics
Coatings
Miscellaneous Uses

tics and mixtures of plastics also are developing functional and economic markets ranging from direct reuse in the same types of containers to the manufacture of plastic "wood," a strong, rot-proof, and long-lasting material usually made from mixed plastics that can be molded or machined into posts and planks for fencing, furniture, and other structures for outdoor use.

Although the Food and Drug Administration, Washington, D.C., has little problem with pre-consumer plastic waste from in-factory trim being used in food-contact packaging, as long as it is kept clean and under control, the use of post-consumer-recycled (PCR) plastics in food-contact packaging is still subject to development.

Containers with PCR content may be used for food contact without any clearance from FDA as long as no food additives will result. However, for peace of mind, suppliers developing these materials for food-contact outline the specific conditions under which the recycled resin will be used and request an advisory opinion from the agency. This is issued in the form of what is called a Letter of No-objection. It is applicable only to the material (and company) specified and should not be construed as a carte blanche for any other company producing a recycled-content resin.

Currently, the agency has issued Letters of No-objection for recycled high-density polyethylene (RHDPE) and RPET. RPET is by far the more common and is being produced by a supercleaning or a methanolysis process, which breaks the resin down into basic monomers or molecules and then repolymerizes it. For RHDPE, tight controls and use of selected bottle sources appear to be key. Another popular way to reuse plastic materials is to line the food-contact surface of a film or container with a virgin layer of plastic, which generally achieves the necessary barrier to indirect additives from the recycled outer layer.

Paper and Paperboard

One of the most vigorously recycled groups of packaging materials includes paper, paperboard, and corrugated. A principal reason is that out of the approximately 600 paper mills in the United States, 200 now depend almost entirely on waste paper for their raw material and another 300 use it as 10 to 50 percent of their mix.

According to figures from the AFPA, in 1995 about 43.3 million short tons (39.3 million metric tons) of waste paper was recovered by the industry, up 4 percent from 1994, the largest annual jump in U.S. history [7]. This is a 45 percent recovery rate, well on the way to the industry's goal of 50 percent recycling by the year 2000 (see Table 21.3) [8]. About 75 percent of the paper recovered in the United States is recycled into new paper and board. Almost all the rest, 24 percent, is exported, with the remainder going into durable fibre products like wallboard [9].

Such recycled paper waste has always been segregated to some extent, but measures now are being taken to keep not only newspapers and old corrugated in separate piles, but also fine papers and paperboard from offices and other up-grade outlets, too. The result is an increasing capability to blend these materials into recycled papers and boards with higher properties, but lower costs.

Industry observers believe that the paper field is now nearing its maximum recycling capability. For one thing, there is little thought of recycling sanitary paper or some types of heavily contaminated food containers. For another, a substantial amount of corrugated and fibreboard end up in “permanent” products such as storage boxes or as vital books and documents that are retained. Finally, paper fibre wears out and loses most of its strength after a few recycles. Therefore, it must be mixed with new wood fibre in many applications, the amount varying considerably depending on the required strength.

Nevertheless, 100 percent recycled paperboard is widely specified, especially for folding cartons. To promote its use, 10 manufacturers have formed the 100% Recycled Paperboard Alliance (RPA-100%), New York, and recruited packaged goods companies to publicize their 100 percent recycled board products and packaging with consumers by identifying it with an RPA-100% symbol (see Figure 21.2).

TABLE 21.3. Recycling Rates.

	Percentage recycled	
Material	1980	1995
Glass	5	37
Steel Cans	5	60
Aluminum Cans	37	62
Paper/Paperboard	27	45
Plastic Bottles	4	22

Figure 21.2.
Thousands of consumer products from more than thirty-two companies have added the RPA-100% logo to their packaging to tout the use of 100 percent recycled paperboard. (Source: 100% Recycled Paperboard Alliance, New York, used with permission.)

Steel

Modern steel depends upon recycling, since all new steel is created from a relatively high percentage of recycled material. Steel production is rising and each ton of recycled steel saves 2,500 lb (1,134 kg) of ore, 1,000 lb (453.6 kg) of coal, and 40 lb (18.1 kg) of limestone [10]. Used cans are a good scrap source because the steel is very clean, low in manganese, carbon, and phosphorous. In addition, the material's magnetic properties makes it easy to separate cans from MSW. Scrapped steel drums also are recycled at the end of their six- to eight-trip life.

From packaging, about 56 percent of food, paint, and aerosol cans were recycled in 1995 [11], a percentage that is expected to grow as the Steel Recycling Institute (SRI), Pittsburgh, Pennsylvania, expands its educational program and works with scrap dealers and recycling center operators to convince them to add cans to their mix. To raise the profile of steel can recycling, SRI has developed a chasing arrows "Steelmark" packagers can use to encourage consumers to recycle (see Figure 21.3). On aerosols, the mark appears with a disposal statement, which instructs consumers to empty the can before recycling it.

Steel cans are recycled in two ways. Incinerated cans are exported via scrap

Figure 21.3.
The "Steelmark" logo encourages recycling of steel cans including aerosols. On aerosols, an accompanying statement advises that a growing number of recycling programs accept steel aerosol cans, but the containers should be completely emptied before being thrown in the recycling bin. (Source: Steel Recycling Institute, Pittsburgh, used with permission.)

dealers to British Steel Strip Products, which has a process for recycling the material into new cans. Nonincinerated cans can be de-tinned to yield a very high-value scrap used to make stainless steel and other high-quality products.

About nineteen divisions of six domestic steel companies now recycle cans and drums. Each mill has its own specifications, but in general, all will accept either tin-coated or de-tinned containers, shredded or whole, loose or baled. Aluminum ends are acceptable, but material must be free of nonmetallic materials.

Aluminum

In March 1968, before most packagers had ever heard the word recycling, Reynolds Metals Co., Richmond, Virginia, paid $50,000 for almost 1 million lb (453,600 kg) of aluminum beverage cans. The entire industry and the public responded and in 1995, 100.7 billion beverage cans were shipped and 62.7 billion were recycled. This was a return rate of 62 percent, according to the Aluminum Association (see Table 21.3) [12]. Making a new can from recycled aluminum requires only 5 percent of the energy needed to make a can from raw ore, an enormous savings.

Glass

Glass is a container material that has been recycled almost since the very beginning of glass packaging. This is because glass manufacture works best when it is started with a charge of broken glass called "cullet." The old glass melts at a lower temperature than the raw materials and improves the fusion process.

Glass containers are completely recyclable and about 37 percent were collected for reuse or recycling in 1995, according to the Glass Packaging Institute, Washington, D.C. [13]. A typical glass container contains between 24 and 60 percent recycled content. Recycled glass containers are sorted by color and must be free of any ceramic contamination.

Wood

Broken pallets and discarded crates that cannot be repaired are a major source of recovery for wood. Nearly half of the roughly 400 members of the National Wooden Pallet and Container Association, Washington, D.C., recondition pallets for reuse and recycle badly damaged ones. Discards are mostly ground into compost, animal bedding, and boiler fuel. However, there is a growing application wherein the ground wood is mixed with a plastic resin and turned into pallets and skids that are lightweight and very strong. These, in turn, can be reground and turned back into the same type of pallet or skid.

A number of companies in the growing plastic-pallet industry also collect and recycle their worn-out carriers.

Source Reduction

One obvious way to reduce the amount of packaging in existence is to use less or none at all, a technique called source reduction. This minimization of materials is not new. Following World War II, when military budgets were drastically reduced and common commodities no longer needed the ultimate in packaging to survive in climates ranging from hot, wet jungles to frozen arctic wastes, the Armed Forces eliminated some of its standard super-packaging in favor of that used for civilian federal purchases. Other commodities, such as piping and steel fabrications, were shipped bare with only a tag to carry source and address information.

Some of this packaging reduction is now creeping into the distribution of industrial and consumer goods through two types of innovation. First is the growth of warehouse and club stores where the distribution package generally doubles as the display container, and larger quantities of product per package often reduce the unit packaging cost. More intriguing, though, is a deliberate attempt by consumer product manufacturers to reduce packaging volume through elimination, lightweighting, redesign, material changes, or concentrating the product.

One approach in consumer packaging has been to eliminate the folding cartons around primary containers of healthcare and toiletry products. Another concept is tray packing and shrink banding robust products to cut the amount of board required in the transport container. Some industrial items, like those in the military, are simply being banded and tagged for transport. In addition, steps are being taken to reduce the mass of product containers themselves. Examples include converting to smaller diameter can ends, reducing film gauges, or replacing rigid containers with flexible.

A major driver is, of course, cost reduction, but if, for example, the wall of a beverage container can be thinned and the end reduced in diameter, the savings are environmental as well. Developments in packaging materials that improve structural strength and barrier properties enable these reductions. Thus, packagers should study their packages periodically to see if less material can be used. It not only is good for the environment, but also makes good business sense.

Packaging Reuse

At first blush, reuse of packaging would seem to be a good environmental solution. Steel drums, for example, are reconditioned and reused many times.

However, the reuse of product packages is not such a simple matter since the American public is separated from the concept of refills by more than two generations. This was made rather clear during the first environmental era when a major soft drink company ran a test to reintroduce returnable bottles. The test area was highly urban, the population not overly prosperous, and there were plenty of stores willing to accept the returns. Payback was unusually high at 10 cents a container. But within weeks, every bottle had disappeared into the trash. Perhaps the public could be retrained. People do turn in aluminum cans in vast numbers and also are setting aside packaging for curbside pickup. But the chances of making a widespread system of consumer returnables work do not appear favorable.

There are other reasons, too. While highly effective washers are available and glass is virtually impervious to penetration by contaminants, plastic and paperboard containers are much more absorbent and hard to clean and keep in shape for more than a single trip. As a result, reusable plastic and paperboard is viewed as largely impractical. However, it should be noted that home refills are expanding in use, particularly for household chemicals. Reckitt & Colman Inc., Montvale, New Jersey, for example, markets 75 percent lighter Smart (save money reduce trash) Pack refills for its Resolve Carpet Cleaner and Lysol Direct Multipurpose Cleaner trigger sprayer containers.

Where use of reusables/returnables really is capturing attention is in transport packaging. It's happening where closed-loop distribution systems can operate between a packager and its vendors or where a small industry can pool containers among many competitors. Plastic tote boxes; intermediate bulk containers (IBCs) of plastic, corrugated, or composite materials, which hold up to 2,000 lb (907 kg) of product, and super sacks of woven plastics, which typically hold 4,000 lb (1,814 kg), are capturing significant applications in powdered and granular materials. Rectilinear tanks of molded plastic also are used for transporting liquids. Where admixtures might occur when such containers are switched from product to product, disposable liners are specified.

Another success has been in ventilated structures of both corrugated and plastic for fresh fruits and vegetables. The latter, somewhat resembling the once-familiar wooden crates, are infinitely easier to clean, maintain, and securely stack. Most of the rigid containers are carried on reusable pallets or have built-in feet.

Biodegradable Packaging

To a generation that believes anything technical is possible, the idea of a package that serves its purpose and then just disappears is very attractive. The concept has been around since the first environmental era and some serious research has been devoted to it. Today, in fact, there are a number of cushioning materials and a few films derived from vegetable matter and used in a specialized applications.

But there are problems with the general premise, which are not easy to overcome. First, a packaging material inherently must protect a product not only from physical damage, but also from environmental damage. In addition, the package must resist any damage from the product itself. Almost all products are exposed to a wide variety of environments in their various transport modes and markets. Products vary even more widely in their pattern of use and/or consumption. A frequently cited example describes a biodegradable bottle of dish-washing detergent designed to begin degrading after a set period of time, which encompasses the product's predicted shelf life. However, a bottle stored under a sink may be exposed to moisture and possibly heat. The same bottle placed on a window sill is exposed to visible and ultraviolet light and heat. Product usage time may vary from customer to customer. The timing of the degradation process might have to be changed repeatedly to suit the properties of different products. The point is that packages can be exposed to a wide variety of degrading factors and, despite research, no one has yet developed a mechanism that can meet all of the variables.

Secondly, degradable packaging requires the proper conditions to deteriorate. And, although commonly thought to provide the appropriate environment, landfills, are in fact designed to minimize degradation of the contents and do so quite successfully. Recent archeological excavation of a number of landfills show that most discards are still highly recognizable in shape and form after as long as forty years.

While research in the area of degradables continues, the better answer is no doubt package recycling or incineration for power generation.

Certification Programs

There are many factors in the relationship between upgrading the environment and packaging measures that can help attain the goal. To get the relationship across to both industrial users and consumers, many countries have created symbols variously called eco-logos or eco-marks to identify packages that are environmentally sound and/or eligible for certain collection programs (see Figure 21.4).

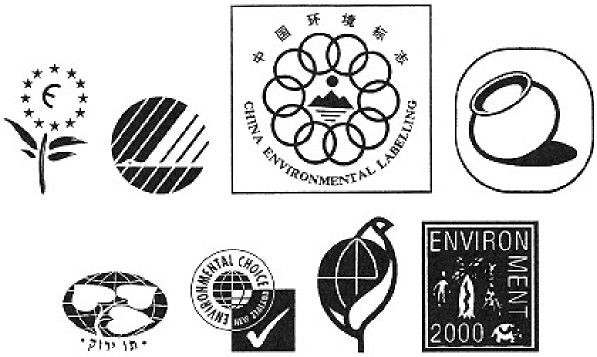

Figure 21.4.
The fact that the environmental movement now stretches around the world is pictured in this small sampling of eco-logos used by different countries to identify acceptable packaging. Shown (top row, l-r) European Union, Nordic Council, China and India; (bottom row, l-r) Israel, New Zealand, Taiwan, Zimbabwe. (Reprinted from Environmental Packaging: U.S. Guide to Green Labeling, Packaging and Recycling, with permission from Thompson Publishing Group, Washington, D.C., 1997.)

In the United States, two organizations certify "green" claims. One, established in 1984 by Scientific Certification Systems (SCS), Oakland, California, can assign two levels of certification to a product and package:

(1) Verification of such packaging attributes as recycled content and biodegradability (see Figure 21.5)

Figure 21.5.
Upon certification of environmental claims, packagers may add Scientific Certification Systems' cross and globe emblem to their packaging. A more stringent level of analysis produces an eco-profile that can be presented on the label as an Environmental Report Card to enable consumers to comparison shop if competing products also have been studied. (Reprinted from Environmental Packaging: U.S. Guide to Green Labeling, Packaging and Recycling, with permission from Thompson Publishing Group, Washington, D.C., 1997.)

(2) Establishment of an eco-profile of all the environmental burdens produced by the manufacture, use, and disposal of a product and its associated packaging

SCS also conducts life-cycle-assessment (LCA) inventories for packagers, a technique used both in Europe and the United States since the 1970s to determine the total environmental impact of a product, including packaging, from its manufacture to final disposal. The number of factors involved are so vast that complex computer modeling is required to assess all of the manufacturing, material, transport, storage, use, and disposal factors involved.

The other U.S. certification program is conducted by Green Seal Inc., Washington, D.C. Founded in 1990 as a nonprofit environmental certification and education entity, it divides products into more than 50 categories and uses Underwriter Laboratories Inc., Northbrook, Illinois, for most of its manufacturing plant inspections. However, Green Seal does not as yet cover packaging, only products.

Foreign Packaging Waste Regulations

Canada

In 1988, Environment Canada established a voluntary certification program, the Environmental Choice Program (ECP), to create a market incentive for manufacturers and suppliers to reduce the environmental burden of their products/services. Now administered by a private organization, the program develops guidelines for various products, which then may apply for a license to use an eco-logo that consists of a maple leaf and three intertwined doves (see Figure 21.6) [14].

Figure 21.6. More product than package oriented, Canada's Environmental Choice Program drafts guidelines for certain product categories. Once finalized, manufacturers, importers, or service providers with a product or service that meets the guidelines may apply for a license to use the logo. When displayed, the logo also must include a statement in French and English citing the relevant guideline, for example, "contains 100% recycled paper." (Reprinted from Environmental Packaging: U.S. Guide to Green Labeling, Packaging and Recycling, with permission from Thompson Publishing Group, Washington, D.C., 1997.)

A year later in 1989, the Canadian Council of Ministers of the Environment (CCME) set a goal to reduce packaging waste 50 percent by the year 2000.

The CCME also established a National Task Force on Packaging, which includes government, industry, consumers, and environmental groups. This group set up a National Packaging Protocol (NAPP) based on six policies [15]:

(1) All packaging should have a minimal effect on the environment.

(2) Packaging should be managed by source reduction, reuse, and recycling.

(3) An educational program should be started to make all Canadians familiar with the functions and impacts of packaging.

(4) The policies should apply to all packaging, including imports.

(5) Regulations would be enforced to achieve compliance with the policies.

(6) All government policies and practices should be consistent with these national policies.

In 1996, CCME reinforced NAPP with a set of Guiding Principles for Packaging Stewardship. Since then, Environment Canada has been working to translate the principles into a model procedure that the provinces could adapt and adopt to guide source reduction, reuse, and recycling. Several models have been created, but at this time, none have been found acceptable to any or all areas of the country.

Europe

In 1994, twenty-four years after it was first proposed, the European Union (EU), formerly called the European Economic Community, finally adopted a Packaging and Packaging Waste Directive. Taking effect in 1996, it covers the EU's fifteen member states, which stretch from Greece to Denmark and from Spain and Portugal to Ireland. Headquarters is the European Recovery and Recycling Association (ERRA) located in Brussels, Belgium.

There are still many details to be worked out, but the main criteria are that all household, commercial, and industrial packaging produced or shipped in the EU must be recovered at a rate of 50 to 65 percent by weight and recycled at a rate of 25 to 45 percent by 1999. In addition, recycling rates may not drop below 15 percent for any particular packaging material.

Packages must be identified as to their material(s) of construction by code letters and numbers organized into seven categories: plastics, paper, metals, wood, textiles, glass, and composites (see Table 21.4) [16]. Member states also must reduce use of materials harmful to the environment, promote clean products and technology, take advantage of available waste-reduction

TABLE 21.4. European Union Voluntary Material Identification System.

PLASTICS		
1	PET	Polyethylene Terephthalate
2	HDPE	High-density Polyethylene
3	PVC	Polyvinyl Chloride
4	LDPE	Low-density Polyethylene
5	PP	Polypropylene
6	PS	Polystyrene
PAPER		
20	PAP	Corrugated
21	PAP	Paperboard
22	PAP	Paper
METALS		
40	FE	Steel
41	ALU	Aluminum
WOOD		
50	FOR	Wood
51	FOR	Cork
TEXTILES		
60	TEX	Cotton
61	TEX	Jute
GLASS		
70	GL	Clear Glass
71	GL	Green Glass
72	GL	Brown Glass
COMPOSITES		
80	C	Paper and Fibreboard/Miscellaneous Metals
81	C	Paper and Fibreboard/Plastic
82	C	Paper and Fibreboard/Aluminum
83	C	Paper and Fibreboard/Tinplate
84	C	Paper and Fibreboard/Plastic/Aluminum
85	C	Paper and Fibreboard/Plastic/Aluminum/Tinplate
90	C	Plastic/Aluminum
91	C	Plastic/Tinplate
92	C	Plastic/Miscellaneous Metals
96	C	Glass/Plastic
97	C	Glass/Aluminum
98	C	Glass/Tinplate
99	C	Glass/Miscellaneous Metals

Abbreviation for the predominant material.

Data source: European Commission.

Source: From *Environmental Packaging: U.S. Guide to Green Labeling, Packaging and Recycling,* Thompson Publishing Group, Washington, D.C., 1997.

initiatives, encourage the use of recycled materials in the production of new packaging, and reduce heavy metals in all packaging. Targets, which have been reexamined on a 5-year basis will go to 10-year goals after the year 2000.

A country can exceed the maximum recycling limit if it can prove the capacity to do so and that the step will not adversely affect international trade. Member states, except France because its 1992 law is identical to the EU Directive, have had to modify existing laws to comply.

Germany will attempt to keep its very high requirement for recycling and its mandate that 72 percent of all beverages must be in returnable/reusable containers. Germany, which initially forbade incineration, has had to permit this disposal method (with energy recovery) and has dropped its mandatory deposit requirement if refillable rates fall below the 72 percent quota.

About 89 percent of German consumers separate packaging waste from the household waste, and 66 percent hold a favorable opinion of the recycling program, which cost an average consumer $32 in 1995. In packaging at point of sale, about 79 percent was collected, 77 percent recycled. All figures were up compared to 1994.

The United Kingdom is still in the process of finalizing its recovery system, operated by the Valpak Working Representative Group, London, which was initiated about 4 years ago, and will seek to raise funds to pay for packaging disposal from packaging manufacturers, converters, and packagers. The result will have to meet the requirements of the EU directive.

The EU guidelines are intended to assist member states in drafting national packaging waste management plans that fit their particular circumstances. A major policy for all is to avoid legislation that creates barriers to trade or distortions in the market. Continuing work on the EU waste disposal plan will be conducted in life-cycle analyses, minimum recycling levels, and material coding programs by the European Committee on Standards (CEN), which will be based in Brussels and include members from ERRA; Britain's Incpen (Industry Committee for Packaging and the Environment), London; and other environmental groups.

Although there is an EU eco-label (see Figure 21.4), it is possible that Germany's Green Dot (der grune Punkt) system may become the universal package coding system in Europe, since it would be desirable to have a single universal recycling symbol rather than one for every country and it is already in use in Austria, Belgium, and France. Devised by Germany's Duales System Deutschland (DSD), Cologne, a private company established to collect and recycle primary packaging materials, as a way to finance its program, participating producers of packaged goods pay fees to use the Green Dot on their packages depending on the material(s) used and sales volume (see Fig-

Figure 21.7.
Germany has two eco-logos, the Green Dot (left) for consumer packaging and the Blue Angel (right) for returnable/reusable transport packaging. (Reprinted from Environmental Packaging: U.S. Guide to Green Labeling, Packaging and Recycling, with permission from Thompson Publishing Group, Washington, D.C., 1997.)

ure 21.7). Most retailers in Germany will not accept goods without this symbol. The rules apply to imported packaged goods, too.

At the end of 1996, DSD's Green Dot had 16,200 licensees and applicants. Germany's other eco-logo, the Blue Angel, is used for returnable crates and other transport packaging (see Figure 21.7). The program and fees are administered by RAL Deutsches Institut für Gütesicherung und Kennzeichnung, Sankt Augustin, Germany, which has established more than 70 product groups and now covers more than 3,800 products, of which at least 10 are foreign [17].

Asia

Most Far Eastern countries created environmental programs in the 1990s and have or are in the process of developing legislation on both consumer and industrial waste. Criteria usually are based on the environmental status of a packaging material and its ease of recycling or incineration. Most have developed eco-logos, which are available for license by foreign as well as domestic packagers (see Figure 21.8).

Japan is one of the most advanced with recycling regulations for bottles and incineration of much burnable waste for power generation.

Figure 21.8.
Unlike many other eco-logos, licensing Japan's product-oriented eco-mark relies more on the attributes of the product itself rather than comparison with competitors or life-cycle assessment. (Reprinted from Environmental Packaging: U.S. Guide to Green Labeling, Packaging and Recycling, with permission from Thompson Publishing Group, Washington, D.C., 1997.)

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Appendix— Useful Conversions

English	Symbol	Multiply by	Metric	Symbol
Angstrom	Å	0.0001	microns	m
degrees Fahrenheit	F	(F - 32) 0.556	degrees Celsius	C
film yield(in.^{2}/lb/mil		0.056	metric yield(m^2/kg/mm)	
foot	ft	0.3048	meter	m
foot	ft	30.48	centimeters	cm
foot, square	ft^2	929.03	centimeters, square	cm^2
foot, square	ft^2	0.0929	meter, square	m^2
foot, cubic	ft^3	0.0283	meter, cubic	m^3
gallon, U.S.	gal	3.7854	liters	L
gallon, U.S.	gal	0.0038	meter, cubic	m^3
inch	in.	25.4	centimeters	cm
inch	in.	0.0254	millimeter	mm
inch	in.	0.000039	microns	m
inch, square	in.^{2}	645.16	millimeters, square	mm^2
inch, square	in^2	6.4516	centimeters, square	cm^2
inch, cubic	in.^{3}	16.3871	centimeter, cubic	cm^3
mil (0.001 in.)		0.025	millimeter	mm
ounce, avdp.	oz	28.349	grams	g
ounce, fluid	oz	29.573	milliliters	ml
ounce, fluid	oz	29.5735	centimeter, cubic	cm^3
ounce, force	oz	0.2780	newton	N
pound	lb	453.6	grams	g
pound/square inch pressure, force	psi	6,895.0	Pascals	Pa
pounds/square foot	lb/ft^2	4.882	kilograms/sq. meter	kg/m^2
pounds/cubic foot density	lb/ft^3	16.020	kilograms/cu. meter	kg/m^3
pounds/cubic foot density	lb/ft^3	0.016	grams/cu. centimeter	g/cm^3
quart, liquid	qt	0.9464	liter	L
U.S. ton, short(2,000 lb)	qt	0.9078	metric ton	t

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About the Authors

JOSEPH F. HANLON

A Rutgers University graduate in chemistry, Joseph F. Hanlon had a distinguished career in packaging, beginning at White Laboratories where he started a packaging department in 1935. He went on to work for Johnson & Johnson, where he also established a packaging department and then held packaging positions at both American Cyanamid and Hoffmann-LaRoche. After 10 years at Hoffmann-LaRoche, he spent another decade consulting in the legal aspects of packaging.

The *Handbook of Package Engineering,* which was first published in 1973, quickly became the basic reference text for packaging professionals and students and was a product of his retirement. He was assisted in this endeavor by his wife, Clara, who learned to type just so she could help him with the manuscript. He revised the book for a second edition in 1983 and was at work on the third edition with his co-author, Bob Kelsey, at the time of his death in 1996. He was elected to the Packaging Education Forum's Packaging Hall of Fame later that year for his contributions to the packaging profession.

ROBERT J. KELSEY

Bob Kelsey holds a degree in food technology, a co-major in bacteriology and minors in both chemistry and process engineering from the University of Massachusetts, a certificate in mechanical engineering from the U.S. Navy, and certificates for courses in electronic engineering from the American Society of Mechanical Engineers, of which he is a Life Member. Initially employed by the U.S. Department of Agriculture, he was one of 60 engineers and technologists that established the Florida citrus concentrate industry. At Curtice Brothers Co. (now Curtice Burns) he rose through quality control and plant engineering to assistant plant superintendent.

Switching to technical journalism, he served as engineering editor of *Food Engineering* and then, moving on to the memorable *Modern Packaging* magazine, was successively engineering editor, editor-in-chief, and executive editor. Since 1973, he has been president of Kelsey Corp., a packaging consultancy based in Ridgewood, New Jersey, which creates new structural packaging designs and packaging machine systems. As founding chairman of an Industry Advisory Committee, he helped establish the Center for Packaging Science and Engineering at Rutgers University, where he has served as an adjunct professor of Packaging Law and Regulation. He is a member of the Packaging Education Forum's Packaging Hall of Fame and a Fellow of the Institute of Packaging Professionals and has authored numerous technical papers and seminars, as well as a book called *Packaging in Today's Society*.

HALLIE E. FORCINIO

Hallie Forcinio is a technical writer/editor specializing in package engineering and technology and environmental topics. Since 1993 she has provided technical services to trade press, corporate, association, and agency clients. Prior to that she was an award-winning journalist on *Food & Drug Packaging* magazine, where she spent 10 years, successively as associate editor, managing editor, and editor-in-chief. Before this, she served in corporate communications for a professional engineering firm.

An active member of the Institute of Packaging Professionals, she was recently elected president of the Cleveland Chapter and has served several times as a judge for the annual Ameristar competition. Other memberships include The International Packaging Press Organization, the American Society of Business Press Editors, and the International Association of Business Communicators. A *cum laude* graduate of Baldwin-Wallace College where she majored in German, she has been listed in *Who's Who in the Midwest, Who's Who of Emerging Leaders in America,* and *Who's Who of American Women.*