PACKAGING, FOOD

1. Introduction

The principal functions of food packaging are to protect the food contents from physical damage, losses, or deterioration, and to facilitate distribution from processor to consumer. Food packaging also must attractively identify the product and perform these functions at minimum system cost because the package itself has no intrinsic value to the consumer. In 2004, food packaging represented $\sim$57% of the United States' >\$110 billion packaging industry.

Food packaging assists product preservation for distribution by reducing spoilage, infestation, contamination, and pilferage; makes economical use of warehouse space; conserves labor in both distribution and marketing; and permits distribution of identified products that can be effectively marketed through self-service retailing. Food packaging deals not only with the materials in contact with the product, but also with secondary and tertiary (unitizing) packages, form, equipment, labor, consumer use, and systems costs.

The choice of packaging for a given food product is circumscribed by a variety of factors, ie, the food characteristics determine the protection needed to prevent deterioration, and the distribution system affects the product's shelf life and therefore imposes additional requirements for its protection. The food package must be attractive, convenient, and identifiable to the consumer. Its costs must be low, and the machinery to produce it must be available. Food packagers must actively consider the ultimate disposal of the used package in selecting food packaging.

Food deteriorates by biochemical, enzymatic, microbiological, and physical vectors. The biochemical vector is the result of interactions of food chemicals because of their proximity to each other. Enzymatic deterioration is biochemical deterioration catalyzed by enzymes naturally present in food. Microbiological deterioration from yeasts, molds, and bacteria is a common food spoilage vector. Damage to food products not associated with biochemical, enzymatic, or microbial spoilage is usually physical, such as gain or loss of water. Elevated water activity in food products increases the rate of biochemical reactions. In food products with high water content, such as fresh produce or meat (see MEAT PRODUCTS), water loss alters physical characteristics and water gain can lead to favorable conditions for microbiological growth. Thus, much of the function of food packaging is to ensure against gain or loss of water. Almost all adverse reactions are accelerated by increasing temperatures.

2. Packaged Food Classification

Approximately one-half of all the food products in the United States are fresh or minimally processed. Fresh food products include meats, vegetables, and fruits that are unprocessed except for removal from the original environment and limited trimming and cleaning. Fresh foods are handled to retard deterioration, which is relatively rapid at ambient or higher temperature. Meats should be chilled rapidly to <10°C (50°F) and most vegetables and fruits are generally reduced to <4.4°C (40°F) by low temperature air, water, or ice.

Minimally processed foods include those that have been altered to help retard deteriorative processes. For example, most dairy products must be refrigerated after pasteurization; salt/nitrite-cured meats must be kept refrigerated after processing to minimize microbial growth.

Fully processed foods are intended for long-term shelf life at ambient temperature, and include almost all heat processed, dried, etc, foods.

2.1. Fresh Foods. *Meat, Poultry, Fish.* About a quarter of food products in the United States are meats, including beef, poultry, seafood, lamb, veal, and pork. All of these are susceptible to microbiological, enzymatic, and physical changes.

The color of red meat depends on oxygen. The natural color of the meat pigment myoglobin is purple. The bright red color of the fresh-as-cut meat is from oxymyoglobin. To preserve red meat, the objectives are to retard microbiological enzymatic and biochemical spoilage and weight loss, and to deliver red color at the consumer level.

In distribution channels, most red meat is packaged under reduced oxygen in high oxygen–water vapor barrier flexible packaging materials to retard deterioration. Fresh meats are transported to retail outlets at temperatures $<10^{\circ}C$ ($50^{\circ}F$) to retard deteriorative processes. At the retail level, exposure to air in gas-permeable packaging permits restoration of the bright red oxymyoglobin color. Oxygen-permeable flexible packaging, such as plasticized poly(vinyl chloride) (PVC) film, permits oxygen into the package while retarding the passage of water vapor. Case ready fresh meat is often packaged under elevated carbon dioxide/oxygen in gas barrier package structures, such as ethylene–vinyl alcohol (EVOH) in combination with polypropylene or polystyrene to retard microbiological growth and retain the oxymyglobin red color.

Poultry, susceptible to microbiological deterioration, is an excellent substrate for *Salmonella*, a pathogen. Therefore, the temperature is reduced as rapidly as possible after slaughter and dressing. Packaging at factory level is in soft film, ie, low density polyethylene, which retard water vapor loss and permits oxygen entry. Much poultry is centrally packaged in case-ready format.

Seafood is packaged to retard weight loss. Packaging for frozen fish generally has low water vapor permeability to permit long-term frozen distribution without freezer burn or surface desiccation. Wrapped or polyethylene-coated paperboard cartons and water vapor barrier flexible films such as polyethylene are employed to package frozen fish.

Produce. Fresh fruits and vegetables must be handled gently because of fragile structures and the ubiquitous presence of microorganisms. Damage to the product surfaces provides channels through which microorganisms can enter to initiate spoilage.

Fresh fruit and vegetable packaging is often in bulk in a variety of traditional wooden boxes and crates, and corrugated fiberboard cases. At or near the retail level, bulk produce may be repackaged in oxygen-permeable flexible materials, such as PVC, with or without a tray of expanded polystyrene containing absorbent pad to help control drip.

2.2. Partially Processed Food Products. Partially processed food products have received more than minimal processing, but still require refrigeration.

Nitrite-Cured Meats. Ham, bacon, sausage, bologna, etc, are cured to reduce water activity, are spiced for flavor, and usually have ingredients to maintain the desired red color. Curing agents include salt, sodium nitrite, and sodium nitrate. Cured meats maintained in an absence of oxygen in vacuum or vacuum plus gas flush have refrigerated shelf lives measured in weeks. Most processed meats are packaged under reduced oxygen on thermoform–vacuum–gas flush–seal systems, usually gas barrier nylon-based, and are distributed under refrigeration. Quantities of cured meats are packaged in oxygen barrier film pouches under inert atmosphere such as nitrogen (see also FOOD ADDITIVES). Some barrier film pouches are packaged in reusable polyolefin thermoformed tubs.

Dairy Products. Dairy products are derived from milk, which must be treated to reduce microbial counts. Pasteurization, a low heat process that destroys disease microorganisms, does not destroy all microorganisms that cause spoilage. Pasteurized dairy products must be maintained under refrigeration. Nonreturnable packages, such as blow-molded high density polyethylene bottles or polyethylene-coated paperboard gable-top packages are most often used for packaging and distributing milk under refrigeration in the United States. In Canada, flexible pouches for fluid milk packaging are made from medium density polyethylene. In recent years, higher heat treatments, eg, ultrahigh temperature (UHT)–short time has been applied in conjunction with clean filling of treated polyester bottles to produce extended shelf life (ESL) packaged products capable of up to 90 days to refrigerated shelf life.

In aseptic packaging, milk is sterilized, ie, rendered free of microorganisms usually by UHT technologies. Simultaneously, high barrier paperboard–foil–plastic-lamination or all-plastic packaging material is sterilized often by hydrogen peroxide. The two are assembled in a sterile environment and the package is sealed to produce sterile milk in a sterile package. The increased heat required for sterilization of the milk can lead to flavors different from those in pasteurized refrigerated milk. Aseptically packaged milk may be distributed at ambient temperature.

Cheese products generally must be maintained under refrigeration using closed flexible plastic, or plastic cups or tubs for packaging. Cured cheeses are often packaged under high CO_2 conditions in gas barrier structures. Ice cream packaging is generally minimal, ie, lacquered or polyethylene extrusion-coated paper-board cartons, molded plastic tubs, or spiral or convolute wound composite paperboard tubs or cartons.

2.3. Fully Processed Foods. Fully processed foods are processed and packaged so that the ambient temperature shelf life can exceed 3–6 months.

Canned Foods. The canning process thermally destroys all microorganisms and enzymes and maintains sterility by hermetic sealing in oxygen- and water vapor impermeable packaging that excludes microorganisms. Whether a metal can, glass jar or barrier plastic tray or pouch is used, the process begins with treating the food product prior to filling. Air that can cause oxidative damage is removed from the interior; however, air removal leads to an anaerobic condition that can foster the growth of pathogenic *Clostridia* organisms. The package is hermetically sealed and then subjected to heating. The package must be able to withstand heat up to 100°C (212°F) for high acid products and

127°C (260°F) for low acid products, which must receive added heat to destroy heat-resistant potentially pathogenic microbial spores. Packages containing low, ∼ pH 4.5, acid foods must withstand pressure or the processing operation must be under precise pressure conditions. The thermal process is calculated on the basis of time required for the most remote portion of the food within the package to achieve a temperature that destroys *Clostridia* spores. After reaching that temperature, the package must be cooled rapidly to retard further cooking and biochemical change.

The package must contain the product, exclude air, and withstand heat. It also must maintain a hermetic seal throughout distribution and ensure that no microorganisms can re-enter the package.

The retort pouch, under development for many years, has a higher surface/volume ratio than a can and employs a heat seal rather than a mechanical closure. Similarly, barrier plastic retort trays have higher surface/volume ratios and are usually heat seal closed. Plastic cans intended for microwave reheating are composed of bodies fabricated from multilayer plastic including a high oxygen barrier material, plus double-seam aluminum closures.

Frozen Foods. Freezing reduces temperature to below the freezing point of water so that microbiological, enzymatic, and biochemical activities are virtually halted. In commercial freezing, the product temperature passes through the transition from liquid water to ice rapidly so that ice crystals are relatively small and do not physically disrupt food cells. The product may be frozen inside or outside of the package. Most freezing processes use high velocity cold air or liquid nitrogen to remove heat from bulk or individually quick frozen (IQF) unpackaged product. The frozen product is then packaged in polyethylene-coated paperboard cartons, or polyethylene or polyethylene-coated paper pouches.

Products frozen in the United States include precooked, processed entrees in meal-size portions packaged in microwaveable crystallized polyester trays with polyester film closures, and overpackaged in printed paperboard cartons or in polyester coated paperboard trays.

Dry Foods. Dry products include those dried from liquid form and engineered mixes of dried components blended to become dry products. In the first category are instant coffee (qv), tea (qv), and milk. The liquid is spray-, drum-, or air-dried to remove water; the presence of water at >1% can lead to browning. Engineered mixes include beverage mixes, eg, sugar, citric acid, color, flavor, and soup mixes, ie, dehydrated soup stock, noodles, and some fat products that become a heterogeneous liquid on rehydration. Products having relatively high fat, such as bakery or soup mixes, must be packaged so that the fat does not interact with the packaging materials. Seasoning mixes that contain herbs and volatile flavoring components can interact with plastic packaging materials such as interior polyolefins. The package must be hermetically sealed, providing a total barrier against both access by water vapor and by oxygen for products susceptible to oxidation.

Fats and Oils. Cooking oils and hydrogenated vegetable shortenings contain no water and so are stable at ambient temperatures. Unsaturated fats and oils (see FATS AND FATTY OILS) are subject to oxidative rancidity; both usually are packaged under inert atmosphere such as nitrogen. Hydrogenated vegetable shortenings generally are packaged in composite paperboard cans with nitrogen to ensure against oxidative rancidity. Edible oils are packaged in blow-molded polyester bottles.

Margarine and butter and analogous bread spreads contain fat plus water and water-soluble ingredients, eg, salt and milk solids that impart flavor and color to the product. Generally, these products are distributed at refrigerated temperatures to retain their quality. Greaseproof, ie, fat resistant, packaging, such as polyethylene-coated paperboard, aluminum foil/paper, parchment paper wraps, and polypropylene tubs, is used for butter and margarine.

Cereal Products. Breakfast cereals are susceptible to moisture absorption and require good water vapor and fat barrier packaging that also retains delicate flavors. Breakfast cereals are packaged in polyolefin coextrusion films in the form of pouches or bags within paperboard carton outer shells. Sugared cereals are sometimes packaged in aluminum foil or barrier plastic, eg, ethylene vinyl alcohol, laminations to retard water vapor and flavor transmission.

Soft baked goods such as breads, cakes, and pastries are highly aerated structures and are subject to dehydration and staling. In moist environments, baked goods are also subject to microbiological deterioration as a result of the growth of mold and other microorganisms. To retard moisture loss, good water vapor barriers such as coextruded polyethylene film bags or polyethylene-coated paperboard are used for packaging.

Hard baked goods, such as cookies and crackers, have a relatively low water and high fat content. Water can be absorbed, and the product loses its desirable texture and becomes subject to lipid rancidity. Packaging for cookies and crackers includes polyolefin-coextrusion film pouches within paperboard carton shells, and polystyrene trays overwrapped with polyethylene or oriented polypropylene film. Soft cookies are packaged in high water vapor barrier laminations containing aluminum foil.

Salty Snacks. Salty snacks include dry grain or potato products such as potato and corn chips, and roasted nuts. These snacks usually have low water content and relatively high fat content. Snack packaging problems are compounded by salt, a catalyst for lipid oxidation in the product formulations. Snacks are often packaged in pouches derived from oriented polypropylene, metallized oriented polypropylene or polyester film structures that have low water-vapor transmission, relying on rapid and controlled product distribution to obviate fat oxidation problems. In recent years, inert gas, ie, nitrogen flushing has been applied to retard oxidative biochemical changes. Some salty snacks are packaged under inert atmospheres in both pouches and rigid containers, such as composite and extrusion blow molded polyolefin barrier canisters, to extend distribution. Generally, light which catalyzes lipid oxidation harms such products, and so opaque packaging is often, but not always, employed.

Candy. Chocolate is subject to flavor or microbiological change. Inclusions such as nuts and fillings such as caramel are susceptible to water gain or loss. Chocolates, which are stable, are packaged in greaseproof papers and moisture–fat barriers, such as polypropylene film (see CHOCOLATE AND COCOA).

Hard sugar candies have very low moisture content. They are sealed in low water vapor transmission packaging such as aluminum foil or oriented polypropylene film.

2.4. Beverages.

Beverages may be still or carbonated, alcoholic or nonalcoholic. The largest quantity of packaging in the United States is for two carbonated beverages, ie, beer (qv) and soft drinks. Both contain dissolved carbon dioxide (qv) creating pressure within the package. The package must be capable of withstanding the internal pressure of carbon dioxide. Coated aluminum cans, and glass and polyester plastic bottles are the most used packaging for carbonated drinks.

Beer is more sensitive than other carbonated beverages to oxygen, loss of carbon dioxide, off-flavor, and light. Most American beer undergoes thermal pasteurization performed after sealing in the package. In recent years, some beer has been packaged in polyester containing added oxygen barrier and oxygen scavengers often in the form of, for example, nylon MXD6. The internal pressure within the package can build to well over 690 kPa (100 psi) at 63°C (145°F), the usual pasteurization temperature. Beer and other carbonated beverages are generally packaged at relatively high speeds; therefore, the packages must be extremely uniform, free of defects, and dimensionally stable.

3. Paper, Metal, and Glass Packaging

3.1. Paper.

The largest volume packaging materials in the United States, accounting for 40% of all food packaging, are paper (qv) and paperboard. Paper consists primarily of cellulose (qv) fibers obtained from wood (qv) by pulping (see PULP). The packaging properties of paper, its strength, and mechanical properties depend on the treatment of the wood fibers and on the incorporation of fillers (qv) and binding materials at the paper mill. The physicochemical properties of paper and paperboard, such as permeability to vapor and gases, are derived from impregnation, coating, and/or laminating. Materials used to enhance barrier include plastics, such as polyethylene, and resins, such as urea–formaldehyde. Laminated and coated papers often warrant the designation of protective materials (see BARRIER POLYMERS). Many converted papers, however, offer little more than protection from light and mechanical damage.

Paper may be used as flexible packaging material components or as material for construction of rigid containers. Flexible packaging applications include bags, usually multiwall; liners; liner substrates; pouches; and overwraps. Some of the more important types of paper used for these purposes include Kraft paper, grease-proof papers, glassines, and, infrequently, waxed papers. Glassine grades are made of tightly knit Kraft paper fibers, highly supercalendered to deliver smooth surfaces capable of accepting coating and print. Greaseproof grades are similar to glassine except for the finishing, and so are not as readily printable. Both glassine and greaseproof papers have good oil resistance.

Rigid paperboard containers are made of paper greater than 0.254 mm (0.010 in.) in caliper and include folding cartons, corrugated fiberboard cases, and spiral and composite wound composite cans. Many paperboard cartons require the use of inner liners or overwraps, made of protective grades of paper, plastic, or aluminum foil laminations.

3.2. Folding Paperboard Cartons.

Valued at > $8 billion, paperboard folding cartons are produced in more than 450 plants, many of which are connected with paperboard mills. Nearly 40% of paperboard folding cartons are food and beverage packaging. Among the 10 largest producers, which account for one-half of the industry sales, are Smurfit Stone, Mead Westvaco, International Paper, Rock-Tenn, and Graphic Packaging. Paperboard folding cartons protect food products from impact and crushing. Certain dense or easily flowing products can be held in shape better by the carton structure. Generally, folding paperboard cartons are used to contain <1.36 kg (3 lb) of product. Paperboard for non-contact food packaging has an interior flexible liner that prevents direct contact between the product and the paperboard of the carton. Up to one-half of the paperboard folding cartons are manufactured from recycled paper and paperboard, used newspapers, and some postconsumer waste papers (see RECYCLING, PAPER).

Carton liners, eg, coextruded polyolefin pouches, help to prevent loose product content sifting and moisture migration. The carton provides a surface for graphic decoration. Polyethylene extrusion coating or, in some cases, polyethylene blend hot melt coatings are used for the interior or exterior of folding cartons, especially if used to contain liquids (see COATINGS). Extrusion coatings can be used with cartons when higher levels of water–water vapor protection are indicated and a film overwrap or inner liner is not desired. Coatings are usually less effective than an additional layer, such as an inner liner.

3.3. Composite Paperboard Canisters. Composite canisters usually consist of spiral or convolute wound paperboard or paperboard-laminated body, the ends of which have been formed to accept paper ends or flanged to seam a metal end ot to heat seal a flexible lid. The package usually has a printed paper label covering the entire body. Composite paperboard canisters using aluminum foil interior are used for packaging refrigerated cookie and biscuit doughs, snack foods, juice concentrates, and dry powders. Convolute wound canisters have been used for cocoa powder, roasted and ground coffee, candy, and ice cream.

3.4. Shipping Containers. A majority of food products are distributed in corrugated fiberboard case trays engineered to meet specifications under quasi-governmental regulations. Corrugated fiberboard is the material most widely used throughout the world for tertiary or distribution packaging. Printed, cut, and fabricated into a box or tray, corrugated fiberboard forms the shipping case. The largest single packaging material in the United States is corrugated fiberboard. Food packaging represents nearly 40% of the total usage. Most converters are linked to paperboard mills. Among the largest producers are Smurfit Stone, Georgia Pacific, Weyerhauser, Inland, and Rock-Tenn.

Polyethylene shrink film wrapping of corrugated fiberboard trays is in common use in and outside of the United States. Equipment erects the trays, fills the trays with primary packages such as cans or jars, wraps the grouping in shrink film, and heat shrinks the combination. Shrink film wrapping keeps primary and secondary packaging materials clean and dry.

3.5. Metal Can Packaging. Nearly 130 billion metal cans are produced annually in the United States, of which 100 billion are two-piece aluminum used for beer and carbonated beverage packaging, but with increasing numbers for still beverage packaging. About 30 billion of the cans are three- and two-piece steel for food containment. The leading merchant can manufacturers are Crown Cork and Seal, Rexam, and Ball.

Two-Piece Cans. Almost all aluminum cans are two-piece drawn and ironed, but some are drawn and redrawn. About one-half of steel cans are two piece.

Draw and iron manufacturing starts with a coil of metal fed into a multiple cupping or blanking press that forms it into shallow cups. These cups are fed into an ironing press, where successive rings or a die stack form the can side wall. More metal is left near the top and bottom to give added strength. In addition to thinning the side wall of the shell, the ironing press imparts the bottom profile. Trimming of the top end follows to produce a can of uniform height. Aluminum and steel drawn and ironed cans are manufactured by essentially the same process.

Inside coatings to protect both the metal and the contents are applied to the can by an airless spray gun. After application, the cans are baked in an oven to remove the solvent and cure the coating.

Three-Piece Cans. Most steel cans are three-piece, ie, a body and two ends. In the past, solder was used to bond the longitudinal seam or "tin" cans, but tin-plate has been replaced by chrome/chrome oxide, and solder has been replaced by welded side seams.

For welded side-seam cans, sheets of steel are coated, baked, and slit into body blanks. The blanks are fed into the bodymaker, where the edges are cleaned to remove any interfering layer, where the steel is welded. The blank is formed into a cylinder with the edges overlapped at the side seam and tack welded together. The cylinder is then passed between rotating wheel electrodes, which weld each side of the seam. Side-seam coating coverage is achieved by applying a powdered epoxy material to both sides of the seam immediately after welding. Residual heat from the weld fuses and cures the stripe.

The cylindrical body then travels to the flanger where the top and bottom edges are curled outward to form the flange. Roll or die-necking are incorporated to reduce the can body diameter on each end in combination with flanging.

When the flanged, or necked and flanged, bodies leave the flanger after having received the topcoat spray and bake, they proceed to the double seamer, where one end is applied.

Protective Coatings. The primary function of interior can coatings is to prevent interaction between the can and its contents. Exterior can coatings may be used to provide protection against the environment, or as decoration to give product identity as well as protection.

Enamel is applied to steel in the flat before fabrication if for three piece cans. Cans manufactured by the draw and ironing operation must be coated internally after fabrication because of the metal deformation with surface disruption that takes place.

Types of internal enamel for food containers include oleoresins, vinyl, acrylic, phenolic, and epoxy–phenolic. Historically, can lacquers were based on oleoresinous products. Phenolic resins have limited flexibility and high bake requirements, but are used on three-piece cans where flexibility is not required. Vinyl coatings are based on copolymers of vinyl chloride and vinyl acetate dissolved in ketonic solvents. These can be blended with alkyd, epoxy, and phenolic resins to enhance performance. Flexibility allows them to be used for caps and closures as well as drawn cans. Their principal disadvantage is high sensitivity to heat and retorting processes; this restricts their application to cans which are hot filled, and to beer and beverage products.

Epoxy phenolic coatings either are made by blending of a solid epoxy resin with a phenolic resin or are the products of the precondensation of a mixture of two resins. A three-dimensional (3D) structure is formed during curing, which combines the good adhesion properties of the epoxy resin with the high chemical resistance properties of the phenolic resin. The balanced properties of epoxy phenolic coatings have made them almost universal in their application on food cans.

Vinyl organosol coatings, which incorporate a high molecular weight thermoplastic PVC organosol dispersion resin, are extremely flexible. Soluble thermosetting resins, including epoxy, phenolic, and polyesters, are added to enhance the film's product resistance and adhesion.

Two basic methods are used for the application of protective coatings to metal containers, ie, roller coating and spraying. Roller coating is used if physical contact is possible, eg, coating of metal in sheet and coil form. Spraying techniques are used if physical contact is not possible, eg, to coat the inside surface of two-piece drawn and ironed can bodies (see COATING PROCESSES, SURVEY).

Coatings that are applied wet must be dried after application by solvent removal, oxidation, and/or heat polymerization. Using powder coating, the resin is applied dry in the form of a fine powder, usually under the influence of an electrostatic field. Powder coating is used where heavy coatings are required, eg, in the protection of welded side seams where the bare metal that exists in the weld area must be covered. Curing is usually by infrared (ir) radiation or high frequency induction heating.

Polyester and polypropylene films have been laminated ($\sim$1991) to base steel sheet to impart protection to the metal. These laminated metals are used to make three- or two-piece drawn cans.

Environmental Aspects. More than two-thirds of aluminum cans are recaptured and returned for recycling into more cans. Because of the heat of melting, the use of postconsumer recycled cans is safe for beverage contents. Not only does recycling save on mass of materials, it also saves the energy of manufacture from aluminum ore.

Because of the vast quantities of scrap steel available from automobiles and appliances, recycling of steel cans has been growing at a relatively modest rate. A third of steel cans are returned and remelted.

3.6. Glass Packaging. Glass is used for carbonated beverages, beer, and still beverage packaging. This $4.5 billion industry is declining in importance because of weight, relative fragility, and energy requirements. Glass is recyclable, and so cullet, or crushed reused glass, is a part of every raw material batch (see RECYCLING, GLASS). Glass is virtually chemically inert and impermeable.

Protective coatings capture or retain some of the original strength of glass containers and delay deterioration. Coatings include hot end treatments in which newly formed hot bottles are subjected to an atmosphere of vaporized metallic compound. This atmosphere reacts with the glass surface, chemically bonding to form a primer that provides permanency to the cold end treatment. The second step of the protective coating, usually an emulsion of polyethylene, is applied after the cooling section of the annealing layer, usually at a bottle temperature of ~149°C (300°F). The second coating imparts lubricity to the container surface. This prevents abrasions or other surface damage from bottle-to-bottle or bottle-to-guide rail contact during normal package handling.

To produce glass bottles or jars, the mixture is prepared in unit batches. Mixing is critical because complete homogeneity of the batch is necessary to produce quality glass. Cullet is added to the batch, usually at discharge from the mixer. The cullet must be of the same color and basic composition, and be free of contamination, such as metal bottle caps and tramp metal scraps.

Molten glass moves through the melter to the refiner, where the glass is conditioned for uniform temperature and for release of dissolved glasses to remove seeds and blisters. The molten glass is cooled and conditioned for equalization of temperature throughout the stream. The glass melting process, regardless of the type of furnace or energy source, is designed to supply a definite tonnage of glass per unit time. Continuous regenerative type furnaces fired with either natural gas or fuel oil commonly are used for melting container glass. Electric melting furnaces also are utilized in glass container manufacturing.

At the gob feeder, the forming operation begins. The gob feeder delivers a glass gob shaped such that it enters the blank mold without excessive mold contact, distortion, or reshaping of the glass. Shears cut off a gob of glass. The gob is fed to either a blow and blow, press and blow, or press-only forming operation to produce a container.

In blow and blow operations, the gob of glass (parison) is delivered from the feeder to the blank mold. The gob drops through a guide funnel into the blank mold in the inverted position. Air is applied to settle the gob into the finish, and air is blown in to complete the parison shape.

Press and blow operations are used to produce wide mouth and some narrow neck containers, including beer bottles. The difference between the press and blow operation and the blow and blow operation is that the parison is pressed into shape by a plunger that fills the complete void in the parison.

The rapid transfer of heat and the mechanics of blowing the bottle creates both thermal and mechanically induced stresses in the newly formed bottle. To relieve the stresses, the newly formed bottles are put through a controlled temperature heat annealing process.

4. Plastic Packaging

Plastic materials represent ~20% by weight of all package materials, about one-half for film and one-half for bottles, jars, cups, tubs, and trays. The principal materials used are HDPE for bottles, low density polyethylene for film, polypropylene (PP) for film, and polyester for both bottles and films.

Plastic packaging materials are thermoplastic, ie, reversibly fluid at high temperatures and solid at ambient temperatures. These materials may be modified by copolymerization, additives in the blend, alloying, and surface treatment and coating. Properties of principal plastic packaging materials are given in Table 1.

4.1. Materials. *Polyethylene. Low Density Polyethylene.* This film is slightly cloudy, has high tensile strength and good water-vapor barrier properties, but high gas transmission. It is employed for shrink and stretch bundling, as drum and case liners, and to package bread, fresh produce, and low sensitivity food products. The material may also be extrusion blow molded into soft sided bottles.

The density of LDPE for film ranges from <0.90 to ~0.93 g/cm^3. The resin is melted in a heated extruder and converted to film by extruding through a circular die. The resulting tube is collapsed and slit into film ranging in gauge from <0.25 mm to >0.75 mm. Some monolayer and coextruded polyethylene films are produced by slot-die casting. Because of its extensibility, LDPE film is usually printed on central impression-drum flexographic presses; modern rotogravure presses permit finer printing.

Linear Low Density Polyethylene. These films from linear LLDPE resins have 75% higher tensile strength, 50% higher elongation-to-break strength, and a slightly higher, but broader, heat-seal initiation temperature than do films from LDPE. Impact and puncture resistance are also improved over LDPE. Water vapor and gas-permeation properties are similar to those of LDPE films.

Linear low density polyethylene films are used in many of the same packaging applications as LDPE. The greater film extensibility permits the printing of small bags by 1 or more of 800 American companies.

High Density Polyethylene. These resins range in density from 0.93 to 0.96 g/cm^3 and are more translucent and stiffer than LDPE films, with lower elongation to break. Water vapor and gas permeabilities are slightly higher than those of LDPE. Softening and melting points are high. HDPE materials are not easily sealed on flexible packaging equipment. The HDPE film replaces paper sacks for retail grocery and department store take out bags. The most important packaging use for HDPE is for extrusion blow molding of bottles for milk, water, and nonfoods, such as liquid detergent, motor oil, etc, by companies such as Graham and Continental.

These coextrusions with ethylene–vinyl acetate copolymer or ionomer are widely used as liners in food cartons. High density polyethylene film is produced by blown-film extrusion methods, often blowing downward because the weight of the film could cause collapse of an upwardly blowing bubble, as used for low density polyethylene film.

Polypropylene. Polypropylene film is produced as either unoriented (CPP) (cast polypropylene) or oriented (OPP) films. Because of extremely poor cold-temperature resistance and a very narrow, short, heat-seal temperature range, CPP film is not widely used for packaging. In film form, the material is a good heat sealant for packages that have later high temperature requirements, eg, retorting. It is used as a transparent bag material for textile soft goods, twist wrap for candy, and other applications. Coextruded films of PP/PE and CPP are used to separate sliced cheese. Unoriented PP is made by extrusion through a slot die.

Oriented polypropylene film (OPP) may be classified as heat-set and non-heat-set, blown and tentered, coextruded and coated. Orientation improves the cold-temperature resistance and other physical properties. Heat-set biaxially oriented polypropylene film (BOPP) is the most widely used protective packaging film in the United States. It is used to wrap bakery products, as lamination plies for potato and corn chips, and for pastas and numerous other flexible pouch and wrapping applications. Nonheat-set OPP is used as a sparkling, transparent shrink-film overwrap for cartons of candy.

Oriented polypropylene film may be manufactured by blown or slot-die extrusion processes. In the slot-die tenter-frame process, polypropylene film is extruded through a flat-die and stretched or oriented in the machine direction. The film is then reheated, gripped along its edges, and stretched outwardly while in longitudinal motion to impart transverse directional orientation. To impart heat-seal properties, it may be coextruded or coated with acrylic or poly(vinylidene chloride) (PVDC). In the lesser-used double-bubble blown film process, the resin is extruded through a circular die, cooled, reheated, and blown again to produce a balanced, biaxially oriented, heat-set film. Film may be coextrusion blown to provide a heat-sealing coating. Film may also be coated with poly(vinylidene chloride) to impart water-vapor, gas-barrier, and heat-sealing properties.

OPP producers have expanded the core, creating a foam structure with lower density, greater opacity, and a stiffer, more paper-like feel. Vacuum metallization increases opacity and water vapor barrier properties.

Oriented polypropylene film has excellent water vapor barrier but poor gas barrier properties; excellent clarity, or opacity in newer forms; and good heat-seal properties in packaging applications.

Poly(vinyl chloride). To be converted into film, poly(vinyl chloride) (PVC) must be modified with heat stabilizers and plasticizers, which increase costs. Plasticized PVC film is highly transparent and soft, with a very high gas-permeation rate. Water vapor transmission rate is relatively low. At present, PVC film is produced by blown-film extrusion, although casting and calendering are employed for heavier gauges.

The principal packaging use of PVC film is as a gas-permeable, but water vapor impermeable, wrap for red meat, poultry, and produce. Sparkle and transparency, combined with the ability to transmit oxygen to maintain red-meat color, offer advantages in these applications.

Polyester. Poly(ethylene terephthalate) (PET) polyester film has intermediate gas and water vapor barrier properties, very high tensile and impact strengths, and high temperature resistance (see POLYESTERS, THERMOPLASTIC). Applications include use as an outer web in laminations to protect aluminum foil. It is coated with PVDC to function as the flat or sealing web for vacuum/gas flush packaged processed meat, cheese, or fresh pasta.

Polyester is manufactured by extrusion through a slot die and biaxially oriented by stretching first in a longitudinal, and then in a transverse direction while still hot, ie, tentering. Polyester film cannot be heat sealed by conventional methods and is either coextruded or coated for heat sealing. Being heat resistant and almost inextensible, polyester film is used as a substrate for vacuum metallizing and silica coating, processes that improve moisture and gas properties. Vacuum-metallized polyester film is used for packaging wine (qv) and bulk tomato and fruit products.

Nylon. Nylon is the designation for a family of thermoplastic polyamide materials that in film form are moderate-oxygen barriers. The gas-barrier properties are equal to odor and flavor barrier properties important in food applications. Nylon films are usually tough and thermoformable, but are only fair moisture barriers (see POLYAMIDES, GENERAL).

Nylon films are used in lamination or coated form to ensure heat sealability and enhance barrier properties. The largest uses are as thermoforming webs for twin-web processed meat and cheese packaging under vacuum or in an inert atmosphere. Other uses include bags for red meat, boil-in-bags, bag-in-box for wine, and as the outer protective layer for aluminum foil in cookie and vacuum coffee packages.

Poly(vinylidene chloride). Poly(vinylidene chloride) (PVDC), most of which is produced by Dow Chemical, is best known in its saran, a PVC-copolymerized form. As solvent or emulsion coating, PVDC imparts high oxygen, fat, aroma, and water vapor resistance to substrates such as oriented polypropylene, polyester, and nylon.

Of the common commercial resins and films, PVDC has the best combination of water vapor and oxygen-barrier properties. High crystallinity confers resistance to the permeation of odors and flavors, as well as to fat and oil. Because of its high chloride content, PVDC tends to corrode processing equipment, which increases manufacturing costs and also leads to environmentalist objections. Unlike other high oxygen-barrier materials, PVDC is almost insensitive to water and water vapor.

Copolymer film is produced by extrusion blowing followed by water quenching. In-line, the film is blown, crystallized, and oriented. The PVDC copolymer film is difficult to produce.

Saran film is used to wrap cheese and occasionally for vertical form–fill–seal chub packaging of sausage and ground red meat. Mostly, it is used as the high barrier component of laminations not containing aluminum foil. It is rarely used alone in commercial packaging because it is difficult to seal.

Polystyrene. Polystyrene package film has excellent clarity, stiffness, and dimensional stability. Because of high permeability to water vapor and gases, it is suited for packaging fresh fruit and vegetables requiring the presence of oxygen. Packaging applications are limited to folding-carton windows, overwraps for tomato trays, lettuce wrapping, etc.

Expanding polystyrene resin prepared by blending with gas delivers an opaque, low density sheet useful for beverage-bottle and plastic can labels as a water-resistant paper substitute.

Other Films. Although commercially less important than polyethylenes and polypropylenes, a number of other plastic films are in commercial use or development for special applications, including ethylene–vinyl acetate, ionomer, and polyacrylonitrile.

Ethylene vinyl acetate copolymer (EVA) forms a soft, tacky film with good water vapor barrier, but very poor gas-barrier properties that serves it well for packaging fresh-cut produce. It is widely used as a low temperature initiation and broad-range, heat-sealing medium. The film also serves for lamination to other substrates for heat-sealing purposes.

Ionomers (qv), often known by their trade name Surlyn (Du Pont), are ionically cross-linked thermoplastics derived from ethylene–methacrylic acid copolymers. Ionomer films are tough, extensible, and impact resistant with excellent heat-seal and hot-tack characteristics. Extruded on other substrates, ionomer films are used as the heat-sealing component.

Polyacrylonitrile (PAN) films have outstanding oxygen and CO_2 barrier properties, but only modest water vapor barrier properties. They are for processed-meat and fresh pasta packaging laminations where an oxygen barrier is required for vacuum or gas flush packaging.

4.2. Coextrusions. In coextrusion, two or more thermoplastic resin melts are extruded simultaneously from the same die. Coextrusion permits an intimate layering in precisely the quantities required to function. Incompatible plastic materials are bonded with thermoplastic adhesive layers. Coextruded films may be made by extrusion-blowing or slot-casting of two, three, or more layers, eg, AB or ABA. Slot-casting is capable of combining up to 11 layers, but most equipment is used for the simple AB, ABA, and ABC or ACBCA configurations, where C is the adhesive layer. In the simplest combinations, oriented polypropylenes are coextruded with copolymer heat-seal layers. Low density polyethylenes are coextruded to impart toughness or slip characteristics.

In more complex combinations, HDPE, LDPE, and EVA resins are coextruded to produce stiff, heat-sealable films to be used as liners in cereal, cookie, and cracker cartons. Films of EVA and white-pigmented LLDPE are used for packaging of frozen vegetables and fruits. In these applications, one layer imparts toughness, opacity, or stiffness, and the other layer adds heat sealability. Coextrusions of nylon with polyethylene in five layers are used for thermoforming where high gas and water vapor barrier are required, eg, medical packaging.

Plastic packaging materials may be classified into rigid and flexible, with an overlapping dividing line between rigid and flexible. Materials determined by caliper or gauge to have thicknesses less than 0.25 mm are generally regarded as being in the flexible category.

4.3. Flexible Packaging. Flexible packaging is composed of both single- and multilayer structures. The latter may be further subdivided into laminated, coated, and coextruded, or combinations of these.

More than one-half of flexible packaging is used for food. Within foods, candy, bakery products, and snack-type foods, such as potato and corn chips, use well over half of flexible packaging. Cheese, processed meat, shrink wraps, condiments, dry-drink mixes, fresh meats, and fresh produce represent smaller applications.

Over 1000 firms participate in the flexible packaging industry in the United States. Manufacturers process the plastic resin into film, a unit operation sometimes assumed by the converter, depending on the material. The processes of slitting, printing, coating, laminating, coextruding, and fabricating into preformed pouches and bags are performed by converters.

Fabrication. Flexible packaging materials may be mono- or multilayer. Monolayer materials are usually films that have been produced by polymer resin melting and extrusion.

Extrusion of polyethylene and some polypropylenes is usually through a circular die into a tubular form, which is cut and collapsed into flat film. Extrusion through a linear slot onto chilled rollers is called casting and is often used for polypropylene, polyester, and other resins. Cast, as well as some blown, films may be further heated and stretched in the machine or in transverse directions to orient the polymer within the film and improve physical properties such as tensile strength, stiffness, and low temperature resistance.

In coextrusion, two or more plastic melts from different extruders are combined into a single die in which the melts are joined. Coextrusion permits precise, small quantities of plastic materials to be intimately bonded to each other.

Free mono- and multilayer films may be adhesive- or extrusion-bonded in the laminating process. The bonding adhesive may be water or solvent based. Alternatively, a temperature-dependent polymer-based adhesive without solvent may be heated and set by cooling. In extrusion lamination, a film of a thermoplastic, such as polyethylene is extruded as a bond between the two flat materials, which are brought together between a chilled and backup roll.

Flexible materials are printed in roll form by rotogravure, flexographic, and web offset printing. In rotogravure printing, a cylinder is engraved with minute depressions or wells that accept dilute solvent-based inks by capillarity. When contacted by the packaging material, the ink is drawn from the wells to the printing surface and the solvent is evaporated to set the ink. In the increasingly popular flexographic printing, the design is elevated above the cylinder surface using rubber-like materials. In offset printing, oil-based ink is in a planographic attitude and printed or offset onto a rubber blanket from which the ink is later removed to the substrate to be printed. Rotogravure printing cylinders are usually considerably more expensive than flexographic printing plates. Offset printing plates are even less expensive. The detail produced by rotogravure and offset is finer than that produced by flexography. Rotogravure is usually used for long production runs and high resolution reproduction, whereas flexography is used for shorter runs and bolder design, and offset is applicable to short run fine design. Both flexography and rotogravure are used to print flexible packaging in the United States. Coatings applied by printing or extrusion protect the printed surfaces.

Some flexible packaging is fabricated by converters into bags and pouches. Bag material is either small monolayer or large multiwall with paper as a principal substrate. Pouches are small and made from laminations. Bags usually contain a heat-sealed or adhesive-bonded seam running the length of the unit and a cross-seam bonded in the same fashion.

Applications. Preformed bags are opened by the packager, filled with food product, and closed by adhesive, heat sealing, clipping, stitching, etc.

A small quantity of flexible packaging material, usually oriented polypropylene, shrink polypropylene, or polyethylene, is used to overwrap paperboard cartons. The film is wrapped around the carton and sealed by heating. Products such as "boxed" chocolates, candies, and cookies are overwrapped, sometimes by a printed film.

Some heavier gauge flexible materials, usually containing nylon, are thermoformed, ie, heated and formed into 3D shapes. Such structures are used to provide high gas-barrier, heat-sealable containment for processed meat or cheese.

Large quantities of flexible packaging materials are employed in horizontal form–fill–seal machines to enclose contents, sometimes with a hermetic seal. The web of material is unwound and folded so that its longitudinal edges are in contact. Meanwhile, the product is conveyed at the same speed as the flexible packaging material into the tube. The two edges are heat-sealed and transverse heat seals are formed between the product units. This system is used for overwrapping, as well as for unit packaging for candies, cookies, and crackers.

In a variant of the horizontal form–fill–seal operation, the material, moving in a horizontal direction, is folded on itself vertically. Vertical sections of the two faces are heat-sealed to each other to form a pouch, which may then be filled. The pouch, usually made from film or paper bonded to aluminum foil plus a plastic laminant and heat sealant, is closed by a heat seal. This type of pouch gives high moisture and oxygen protection and is used for moisture- and flavor-sensitive condiments and beverage mixes.

The largest volume of flexible packaging is used in vertical form–fill–seal applications for loose, flowable products such as potato and corn chips, nuts, and roasted and ground coffee. The roll of flexible material is unwound over a forming collar forcing the web into a vertical, tubular shape. By heat-sealing the edges and a bottom transverse seal, an open-top tube is formed. The product is gravity filled, the web is drawn down, and the tube is closed by another heat seal. Vertical form–fill–seal operations use water vapor barrier materials, such as oriented polypropylene film to package moisture-sensitive products.

In applications other than protective packaging, flexible materials are employed to unitize cans, bottles, cartons, or cases. Heat-shrinkable films, such as low density or linear low density polyethylene, are wrapped around groups of bottles or cans, sealed, and exposed to hot air to bind the contents tightly together within the film. In stretch wrapping, an extensible film cohesive to itself, eg, linear low density polyethylene, is wrapped very tightly around the contents. Surface cohesion causes the film wrap to hold to itself. As the stretched film attempts to revert to its original unstretched form, it binds the bundle more tightly.

Numerous variations and other applications are common for flexible packaging materials, eg, oxygen-permeable wraps for fresh red meat and produce; shrinkable, low oxygen permeability bags for meat; and rigid tray closures.

4.4. Semirigid Containers. Most semirigid plastic for packaging is in the form of bottles and jars. Jars have openings approximately the same as those of the body, whereas the neck diameter of bottles is significantly smaller than that of the body.

Fabrication Processes. Injection Molding. Matched metal molds are used in the fabrication of plastic closures, specialty packages, and bottle preforms. In conventional injection molding the plastic resin is melted in an extruder that forces a measured quantity or shot into a precision-machined chilled mold after which the nozzle of the extruder is withdrawn.

The pressure of the extruder forces uniform plastic distribution throughout the mold. Cooling the mold solidifies the plastic with slight shrinkage. The mold is maintained closed by mechanical or hydraulic pressure while the thermoplastic is injected and solidified.

Because cycle time to inject, flow, set, open, eject, and close is finite, and the face area or platen size is limited, the effective molding area is increased by increasing the number of mold cavities so that the number of finished pieces per cycle may be multiplied many times. Injection molds are constructed of metal precision-machined with internal cooling, multiple cavities, and multifaces, and with devices for extraction or ejection of the molded piece.

Returnable distribution cases for carbonated-beverage and milk bottles are injection molded from high density polyethylene or polypropylene–ethylene copolymer. The HDPE and polypropylene–ethylene copolymer cups and tubs for dairy product and specialty frozen food applications are injection molded. High and medium density polyethylenes are injection molded as closures for metal and paperboard composite can closures. Because covers and closures have a high surface area/depth ratio, multilevel or stack molds are used to maximize unit output per cycle. Many bottle and jar closures are injection molded from polypropylene. High impact polystyrene and polypropylene are both injection-molded for refrigerated dairy product and specialty food cup packaging.

Insert injection molding is used to manufacture snap closures for yogurt and ice cream cups and tubs. In insert injection molding, a die-cut printed paperboard or other flat material is placed in the mold. The plastic is extruded around the insert to form a precision skeletal structure.

Injection-molded articles can be decorated by in-mold labeling or by postmold decoration. In the former method, printed film is inserted into the mold cavity before injection. The plastic forms an intimate contact with the graphic material. Postmold decoration includes hot stamping, dry offset printing, and decal printing.

Injection molding is used for the preparation of polyester preforms for blow molding into bottles, eg, carbonated beverages or salad dressing, and jars, eg, peanut butter. Resins such as polyester with narrow melt-temperature ranges require sequential fabrication steps. A blow-molded parison is injected at melt temperature and gently reheated to softening below melt temperature for stretching or blowing into a bottle or jar.

To enhance water vapor or gas barrier properties, layers of different plastics may be injected together or sequentially. Multilayer injection-molded pieces may be prepared as packaging or for blowing into bottle or jar shapes.

Sheet Extrusion and Thermoforming. Sheet for thermoforming and analogous operations is usually formed by extruding the melt through a slot die onto a set of polished chill rolls. The sheet is usually $\sim$150 cm wide. After rapid cooling, the web is coiled or cut into sheets. Polystyrene, PVC, polyethylene, polypropylene, and filled polypropylene are prepared in sheet form by cast extrusion.

Thermoforming involves plastic sheets, thicker than 0.25 mm, followed by forming a reheated sheet in an openface mold by pressure, vacuum, or both sequentially or simultaneously. Sheet of $<$0.25 mm thick is often thermoformed in-line, and filled and sealed with contents, such as processed meats, cheeses, and pastas.

Thermoformable sheet may be mono- or multilayer with the latter produced by lamination or coextrusion, or both. Multilayers are employed to incorporate high oxygen-barrier materials between structural or high water vapor barrier plastics. Both ethylene vinyl alcohol copolymers and poly(vinylidene chloride) (less often) are used as high oxygen-barrier interior layers with polystyrene or polypropylene as the structural layers, and polyolefin on the exterior for sealing to produce expanded plastic, gas may be introduced by blending thermally reactive chemicals which release gas into the resin at the extruder. Extrusion heat initiates the reaction to release gas and expand the melt. Alternatively, gas may be injected into the plastic sheet as it is extruded.

Steam-Chest Expansion. In steam-chest expansion the resin beads in which gas is already present are poured into molds into which steam is injected. The steam increases the temperature close to the melting point and expands within the structure to create beads with food cushioning and insulating properties. Expanded polystyrene is widely used in this process for thermal insulation of frozen food packaging.

Three-Dimensional Packaging. Thermoforming. Thermoforming is the most common method of fabricating sheet into three-dimensional packaging. In conventional thermoforming, the sheet is heated to its softening point or just below the melting temperature. The softened plastic is forced by differential air pressure into an open-top mold to assume the shape of the female mold. The mold is chilled and the plastic sheet solidifies and is then removed from the mold.

The mold is usually prepared with orifices to permit air trapped between the sheet and the mold to escape and ensure uniform, close contact of the plastic with the mold surface. By clamping the sheet beyond the perimeter of the piece, plastic may be drawn from the peripheral areas into the mold, ensuring uniformity. Both pressure and vacuum are employed to force the softened plastic sheet into the mold.

Thermoforming is used for gauges above 6 mm in some nonpackaging applications; for packaging applications gauges are between 0.6 and 2.5 mm. The material is stretched during formation, and so the greater the depth of draw, the higher must be the gauge of the original sheet. Depth of draw, defined as the ratio of piece height to cross-sectional surface area, is a measure of the ability to form deep articles. Although deep-drawn pieces are feasible, thermoforming is best suited to shallow profiles of up to 7.5 cm; deeper draws often result in thin side walls. Any fully or partially tapered shape with an opening equal to or larger than the body can be made.

In commercial practice, packaging is produced from continuous web on intermittent-motion thermoforming–die-cut machines. The web edge is clamped and conveyed into a heating box. If a plastic with a narrow softening temperature is used, heating is carefully controlled from top and bottom. The heated web is conveyed to the forming section, where pressure or vacuum force the softened web into the mold. The mold opens and the web is conveyed to a die-cutting station.

The narrow softening temperature range and structural properties of polypropylene led to the development of special controlled-temperature forming processes called solid-phase pressure forming (SPPF). The polypropylene sheet temperature is brought to above the softening temperature, but well below the melting point and subjected to forming pressures three to five times those used for fabrication of polystyrene.

Conventional thermoforming of polystyrene is a widely used technique for making packages for dairy products and for disposable cups and trays. In recent years, injection molded polypropylene has competed with thermoformed polystyrene for dairy cups.

Thermoforming may be integrated with filling and sealing on thermoform/fill/seal machines operated in-plant by food packagers. The base web is gripped and moved through heating and forming operations. The open-top pieces are filled and a second web of material is heat sealed to the flange of the base by heated pressure bars. Cutting may take place during or after sealing.

Retortable plastic cans and trays, designed for low acid foods, may be hermetically sealed and thermally sterilized up to 125°C. High oxygen-barrier properties are usually required. These cans or trays are constructed of five-layer coextrusions of PVDC or ethylene–vinyl alcohol (EVOH) as the gas barrier layers and polypropylene, with extrudable adhesive layers. The trays must be thermoformed and aged before filling and sealing to minimize heat-seal distortion due to stress, unless melt-to-mold fabrication procedures are employed. Counterpressure and temperature during retorting must be carefully controlled to avoid heat seal distortion.

Melt-to-mold thermoforming overcomes the thermal stresses developed in forming polypropylene sheet. As the plastic is extruded from the slot die and while it is still hot, it is transferred into the mold. To maintain thermal and mass equilibrium, the molds move continuously past the slot from which the melt is discharged and the plastic is formed in the molds. Melt-phase thermoforming has been used to produce monolayer frozen food tubs and wide-mouth snap closures, for fabricating crystallized polyester trays for dual ovenable applications, and for coextruding multilayer structures incorporating EVOH for hot fill, aseptic, and retort packaging of foods.

Blow Molding. In conventional blow molding a single extruder propels the plastic melt through an annular die to form a tubular parison that is delivered into the open mold. The mold closes, pinching off the bottom and gripping the top. An air-blow tube is inserted through the neck opening and pressurized air is blown in to expand the hot, soft plastic to the chilled walls of the mold. Upon setting, the parison drops or is extracted from the mold. Excess flash is mechanically trimmed.

Extrusion blow molding produces narrow-neck bottles from high and low density polyethylene. Bottles with adequate neck finishes are produced. Without good parison control, bottle wall thickness varies, ie, areas of greater diameter have thinner walls, whereas base, shoulder, and neck areas have thicker walls. These bottles may be fabricated with hollow handles. They may be decorated by in-molding labeling, with decals, by screen printing, or by hot stamp or postmold labeling.

Conventional extrusion or coextrusion may be performed on vertical or horizontal rotary or shuttle mold configurations. In shuttle blow molding the extruder and die are in fixed horizontal and vertical position; two or more molds shuttle into and out of position beneath the die. By reciprocating in two planes, the mold may remove a parison and permit the extruder to function continuously.

Horizontal rotary machines employ multiple molds in a horizontal plane on a rotary turret. As each mold approaches the extruder die exit, it opens to accept the parison and then closes. The parison is then blown into the bottle shape. The extruder must extrude on an intermittent basis or be intermittently withdrawn to provide a parison for each passing mold.

Vertical rotary molds also employ multiple molds on a turret but rotate in a vertical plane. As each mold reaches the die exit, it grasps the parison and closes. Because of the vertical spacing between molds, intermittent extruder action is not required. Vertical wheels are used commercially for high volume applications.

Because high oxygen-barrier plastics are generally incompatible with other thermoplastics, extrudable adhesives must be extruded between the layers of multiplayer structures. Scrap can be included within the multilayer structure, provided an extrudable adhesive is incorporated.

Incorporating EVOH as high oxygen barrier with polypropylene is used for packaging tomato catsup, barbecue sauce, mayonnaise, pickle relish, syrups, prepared foods, and other foods. Bottles fabricated from internal and external layers of polypropylene contain EVOH as the principal high oxygen-barrier material.

Extrusion blow molding of polypropylene is not easy because of its narrow softening-to-melt temperature range. Bottle orientation enhances structural strength. For monolayer polypropylene bottles, a two-stage process produces a continuous extrusion of pipe that is cut into fixed parison lengths. The parisons are reheated and stretched longitudinally before circumferential blowing. Impact resistance, gloss clarity, and stiffness are improved, but barrier properties are not.

Plastic with a very narrow melt temperature range, such as polyester and polypropylene are formed into bottles by injection stretch blow molding. A test tube shape is first formed by injection. This preform is transferred to the blow-molding machine and slowly heated to uniform temperature. The heated parison is placed in the blow mold in which it is stretched to induce vertical orientation and blown to shape. Blowing induces horizontal orientation to provide circumferential or hoop structural strength. Stretching and blowing reduce wall thickness, whereas orientation improves structural strength.

Injection stretch-blow molding may be performed on a single one-stage machine in sequence or on two independent sequential two-stage machines. The PET carbonated beverage bottles are usually produced by injection stretch blow molding.

Multilayer injection stretch blow molding has been commercialized for both narrow neck and wide-mouth containers. The basic form is fabricated by injecting multiple layers, such as polypropylene and EVOH plus tie layers, and blowing the parison. Several high oxygen-barrier cans with plastic bodies and ends intended for metal end double seam closing have been introduced. Cans containing polypropylene and EVOH are retorted after filling to resist retort temperatures up to 125°C.

Heat-Stabilized Molding. Recognition of the merits of hot filling foods into plastic packaging, followed by sealing and cooling, has led to a need for high oxygen-barrier plastic containers capable of resisting temperatures up to 85–90°C for brief periods. Resistance to internal vacuum can be achieved by structural design. Plastics with distortion temperatures >100°C, eg, polypropylene and high density polyethylene, may be filled with hot liquid without fear of thermal distortion, although vacuum collapse is an issue. Polyester requires physical modification to resist heat, drying to remove water, partial crystallization, and heat stabilization. In heat stabilization, the container is molded and briefly secured in the mold while at elevated temperature rather than chilled immediately. The crystalline structure of the material is thereby altered to resist moderately elevated temperatures. This technique is employed to produce PET bottles for filling with hot liquids.

Blow-Mold–Fill–Seal System. Some blow-molded bottles are produced in blow-mold–fill–seal operations engineered for aseptic packaging. On blow-mold–fill–seal machines the parison is extruded through a multilayer annular die into a sterile space containing sterile molds. The parison is blown with sterile air and immediately filled with cooled product. After filling, the bottle is closed by heat-seal fusion within the mold and removed from mold and sterile chamber through a small opening protected against contamination by the pressure of sterile air.

This method is slow because of the multiple operations on a shuttle machine. The heat of extrusion sterilizes the bottle, which is not readily achieved after molding. Blow-mold–fill–seal systems are used commercially for beverages and for pharmaceutical packaging.

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Table 1. **Properties of Plastic Packaging Materials**

Material[a]	Specific gravity	Tensile strength, MPa[b]	Elongation, %	Heat-seal range, °C	Water-vapor transmission rate, μmol/(m^2s)	Gas transmission, nmol/(m^2s)	Use temperature, °C	
							Maximum	Minimum
ionomer	0.94–0.96	21–69	350–450	87–204	13–21	1800–3870	71	−73
nylon								
uncoated	1.13–1.14	48–124	250–500	176–260	240–260	21	176–232	−59
saran coated, one side	1.13–1.14	48–124	250–500	176–260	2	4	93	−40
polyester (PET)								
uncoated	1.35–1.39	172–228	120–140		13	40	204	−62
saran coated, one side	1.4	179–214	90–125	135–204	6	3.2	82[a]	−51
metallized	1.35–1.39	172–228	120–140		0.3–1.4	0.32	204	−62
polyethylene								
LDPE	0.910–0.925	6.9–2.4	225–600	121–176	12	2000–6700	65	−51
HDPE	0.941–0.965	21–52	10–500	135–154	3–6.5	260–2000	121	−51
LLDPE	0.915–0.935	24–55	400–800	121–176	12	2000–6700	76–82	−51
LDPE/ 12% EVA	0.94	21–35	300–500	93–148	39	4100–5200	60	−51
copolymer polypropylene								
nonoriented	0.88–0.90	21–62	400–800	162–204	5–6.5	670–3300	121	>0
oriented	0.905	172–207	60–100	[d]	3–4	880	121	−51
oriented and metallized	0.905	131[e]	50–400	[f]	1	24–80	121	−51
poly(vinyl chloride)	1.21–1.37	14–110	5–500	121–176	>40	400–12000	93	0
poly(vinylidene chloride)	1.64–1.71	55–138	40–100	121–148	0.5–3	0.64–14	~ 82[c]	>−18

[a]PET = Poly(ethylene tetraphthalate) LDPE = low density polyethylene, HDPE = high density polyethylene, LLDPE = linear low density polyethylene, LDPE = high density polyethylene.
[b]To convert MPa to psi, multiply by 1450.
[c]Coating softens.
[d]Requires coating or additive.
[e]Machine direction.
[f]Requires coating.