Paper no.: 12
Paper Title: Food Packaging Technology
Module-28: Edible and bio-based food packaging materials

28.1 Introduction

Edible and bio-based food packaging material is produced from edible biopolymers and food-grade additives. The biopolymers can be proteins, polysaccharides (carbohydrates and gums) or lipids. Plasticizers and other additives are combined with the biopolymers to modify the physical properties or functionality of films.

28.2 Historical uses of edible packaging material

The use of edible packaging material has a short history. As an example of edible films, yuba (soy-milk skin) has been traditionally used in Asian countries since the fifteenth century. Wax coatings were applied to citrus fruits in the twelfth and thirteenth centuries, butonly commercially utilized on apples and pears as recently as the 1930s. Wax coatings reduce moisture loss andslow down the respiration of coated fruits and vegetables, resulting in shelf-life extension. Various waxes have been sprayed on the surface of fruits andvegetables as forms of hot-melt wax or emulsions. Lipid coatings (larding) on meatsand cheeses have been used since the Middle Ages for shrinkage prevention.

28.3 Composition of edible packaging material

28.3.1 Film-forming materials

The main film-forming materials are biopolymers, such as proteins, polysaccharides,lipids, and resins. They can be used alone or in combinations. The physical and chemicalcharacteristics of the biopolymers greatly influence the properties of resulting films and coatings. Film-forming materials can behydrophilic or hydrophobic. However, in order to maintain edibility, solvents used arerestricted to water and ethanol.

28.3.1.1 Protein

Proteins are commonly used edible packaging materials. They are macromolecules with specific amino acid sequences and molecular structures. The secondary, tertiary, and quaternary structures of proteins can be easily modified by heat denaturation, pressure, irradiation, mechanical treatment, acids, alkalis, metal ions, salts, chemical hydrolysis, enzymatic treatment, and chemical cross-linking. The most distinctive characteristics of proteins compared to other film-forming materials are conformational denaturation, electrostatic charges, and amphiphilic nature. Protein film-forming materials are derived from many different animal andplant sources, such as animal tissues, milks, eggs, grains, and oilseeds.

28.3.1.2 Polysaccharide

Polysaccharide materials include starch, non-starch carbohydrates, gums, and fibres. The sequence of polysaccharides is simple compared to proteins. However, the conformation of polysaccharidestructures is more complicated and unpredictable, resulting in much larger molecular weights than proteins. Most carbohydrates are neutral, while some gums are mostly negatively charged. Some negatively charged gums, such as alginate, pectin, and carboxy methyl cellulose, show significantly different rheological properties in acidic than inneutral or alkaline conditions.

28.3.1.3 Lipid

Lipids and resins are also used as film-forming materials, but they are not polymers and "biopolymers" is a misnomer for them. Nevertheless, they are edible,biodegradable, and cohesive biomaterials. Most lipids and edible resins are soft-solidsat room temperature and possess characteristic phase transition temperatures. Theycan be fabricated to any shape by casting and moulding systems after heat treatment,causing reversible phase transitions between fluid, soft-solid, and crystalline solid. Because of their hydrophobic nature, packaging material made from lipid has very high water resistance and low surface energy. Lipids can be combinedwith other edible packaging materials, such as proteins or polysaccharides, as emulsionparticles or multi-layer coatings in order to increase the resistance to water penetration.

Biopolymer composites can modify the properties of packaging material and create desirable structures for specific applications. Similar to multi-layered composite plastic films, biopolymer films can be produced as multiple composite layers, such as protein coatings (or film layers) on polysaccharide films, or lipid layers on protein/polysaccharidefilms. This multi-layered film structure optimizes the characteristics of the final film.Composite films can also be created by mixing two or more biopolymers, yielding one homogeneous film layer. Various biopolymers can be mixed together to form a film withunique properties that combine the most desirable attributes of each component.

28.3.2 Plasticizers

In most cases, plasticizers are required for edible packaging materials, especially forpolysaccharides and proteins. These film structures are often brittle and stiff due to extensive interactions between polymer molecules. Plasticizers arelow molecular weight agents incorporated into the polymeric film-forming materials,which decrease the glass transition temperature of the polymers. They are able to positionthemselves between polymer molecules and to interfere with the polymer-polymerinteraction to increase flexibility and processability. Plasticizers increase the free volume of polymer structures or themolecular mobility of polymer molecules. Theseproperties imply that the plasticizers decrease the ratio of crystalline region to theamorphous region and lower the glass transition temperature. The addition of plasticizers affects not only the elastic modulus andother mechanical properties, but also the resistance of edible films topermeation of vapours and gases. Most plasticizersare very hydrophilic and hygroscopic so that they can attract water moleculesand form a large hydrodynamic plasticizer-water complex. For protein and polysaccharideedible films, plasticizers disrupt inter- and intra-molecular hydrogen bonds,increase the distance between polymer molecules, and reduce the proportion of crystallineto amorphous region. Water molecules in the films function asplasticizers. Water is actually a very good plasticizer, but it can easily be lost by dehydrationat a low relative humidity. Therefore, the additionof hydrophilic chemical plasticizers to films can reduce water loss throughdehydration, increase the amount of bound water, and maintain a high water activity.

There are two main types of plasticizers:

1. Agents capable of forming many hydrogen bonds, thus interacting with polymersby interrupting polymer-polymer bonding and maintaining the farther distancebetween polymers chains
2. Agents capable of interacting with large amounts of water to retain more water molecules,thus resulting in higher moisture content and larger hydrodynamic radius.

28.3.4 Additives

Edible films and coatings can carry various active agents, such as emulsifiers, antioxidants, antimicrobials, nutraceuticals, flavors and colorants, thus enhancing food quality and safety, up to the level where the additives interfere with physical and mechanicalproperties of the films. Emulsifiers are surface active agents of amphiphilic nature able to reduce the surface tension of the water-lipidinterface or the water-air surface. Emulsifiers are essential for the formation of proteinor polysaccharide films containing lipid emulsion particles. They also modify surfaceenergy to control the adhesion and wettability of the film surface.

Although many biopolymers possess certain levels of emulsifying capacity, it is necessaryto incorporate emulsifiers into film-forming solutions to produce lipid-emulsionfilms. In the case of protein films, some film-forming proteins have sufficient emulsifyingcapacity due to their amphiphilic structure. Antioxidants and antimicrobialagents can be incorporated into film-forming solutions to achieve active packaging functions. They provide additional active functions to theedible film and coating system to protect food products from oxidation and microbialspoilage, resulting in quality improvement and safety enhancement.

Incorporated flavours and colorantscan improve the taste and the visual perception of quality, respectively. Because ofthe various chemical characteristics of these active additives, film composition shouldbe modified to keep a homogeneous film structure when heterogeneous additives areincorporated into the film-forming materials.

28.4 Film-forming mechanisms

An edible film is essentially a dried and extensively interacting polymer network of a three-dimensional gel structure. Despite the film-forming process, whether it is wet casting or dry casting, film-forming materials should form a spatially rearranged gel structure with all incorporated film-forming agents, such as biopolymers, plasticizers, other additives and solvents in the case of wet casting. Biopolymer film-forming materials are generally gelatinized to produce film-forming solutions. Further drying of the hydrogels eliminates excess solvents from the gel structure. For example, whey protein films are produced from whey-protein gels by dehydration after heat-set or cold-set gel formation. This does not mean that the film-forming mechanism during the drying process is only the extension of the wet-gelation mechanism. The film forming mechanism during the drying process may differ from the wet-gelation mechanism, though wet gelation is the initial stage of the film-forming process. There could be a critical stage of a transition from a wet gel to a dry film, which relates to a phase transition from a polymer-in-water (or other solvents) system to a water-in-polymer system. The complete film-forming mechanisms of most biopolymers after gelation are not clearly determined yet. Several polymer chemistry laboratory techniques are required to identify them, including X-ray diffraction, FTIR spectrometry, NMR spectrometry, electrophoresis, polarizing microscopy, and other polymer analysis methodologies. For extrusion casting (dry process), many thermoplastic properties, such as gelatinization, polymer melting, flow profile, polymer rearrangement and others, should be investigated to predict the film-forming mechanisms.

As examples, potential chemical methods of modifying the film-forming mechanisms of protein-based films include pH changes, salt addition, heat denaturation, solvent changes, chemical modification of the side chains of peptides, cross-linking, and hydrolysis of peptides, irradiation of peptides, and the addition of foreign proteins. For polysaccharide-based films several chemical modifications are available, including salt addition, solvent changes, heat gelatinization, pH changes, chemical modification of hydroxyl groups, cross-linking of polysaccharides, hydrolysis of polysaccharides, and the addition of foreign polysaccharides. Physical modifications of edible films and coatings include lamination, formation of composites, addition of particles or emulsions, perforation, over-coating, annealing heat curing, orientation, radiation and ultrasound treatment.

28.5Functions and advantages

28.5.1 Edibility and biodegradability

The most beneficial characteristics of edible films are their edibility andinherent biodegradability. To maintain edibility,all film components (i.e. biopolymers, plasticizers, and other additives) should befood-grade ingredients and all process facilities should be acceptable for food processing. With regard to biodegradability, all components should be biodegradable and environmentally safe. Human toxicity and environmental safetyshould be evaluated by standard analytical protocols by authorized agencies.

28.5.2 Physical and mechanical protection

Edible films protect packaged or coated food products from physicaldamage caused by mechanical impact, pressure, vibrations and other mechanical factors.Standardized mechanical examinations of commercial film structures are alsoapplied to edible film and coating structures. Such tests may include tensile strength, elongation-at-break, elastic modulus, compression strength, puncture strength, stiffness,tearing strength, burst strength, abrasion resistance, adhesion force, folding enduranceand others. Edible films have lower tensile strength than common plastic films.

Temperature is also an important variable affecting the physical and mechanical properties of edible films and coatings. The physical strength of materials dramatically decreases when temperatureincreases above the glass transition temperature. High relative humidity and largeamounts of plasticizers lower the glass transition temperature of film-forming materials.

28.5.3 Migration, permeation and barrier functions

The quality of most food products deteriorates via mass transfer phenomena, including moisture absorption, oxygen invasion, flavour loss, undesirable odour absorption, and the migration of packaging components into the food. Edible films may wrap these food productsor be located between heterogeneous parts of food products to prevent thesemigration phenomena and preserve quality.

To characterize the barrier properties of edible films, the transmissionrates of specific hazardous migrants should be determined using stand-alone edible films. Edible films possess a wide range of oxygen permeabilityvalues. Certain edible films are excellent oxygen barriers. Except for lipid-basedmaterials, the water vapour permeability of most edible films is generally higher thanthat of common plastic films. All barrier properties of edible films and coatings areaffected greatly by film composition and environmental conditions (relative humidityand temperature).

Plasticizers in edible film-forming materials reduce glass transition temperatures and increase the permeability of most migrants. Oxygen permeability isvery sensitive to relative humidity. At higher relative humidity conditions, oxygen permeability increases substantially. Therefore, it is very important to maintain low relative humidity environments tomaximize the effectiveness of edible films as gas barriers.

Temperature is also an important factor of migration. A temperature increase provides more energy to the migrating substances and increases the permeability. At temperatures far distant from the phase transition, changes of migration coefficients such as permeability and diffusivity follow the Arrhenius equation. At the glass transition and melting temperatures of film materials, most mass transferco-efficient change substantially.

28.5.4 Convenience and quality preservation

Edible films provide many benefits in terms of convenience. Reinforced surface strength of fragile products makes handling easier. Coated fruits and vegetables have much higher resistance against bruising and tissue damage caused by physical impact and vibration. Besides this protective function for foods, edible films are utilized in the food industry to develop single-dose pre-measured pouches.

Quality maintenance and enhancement are also very significant functions of edible films. They can retard surface dehydration, moisture absorption, oxidation of ingredients, aroma loss, frying oil absorption, ripeningand microbial deterioration of food products. In addition to the physical and chemicalquality enhancement, edible films and coatings contribute to visual quality, surfacesmoothness, flavour carriage, edible colour print and other marketing related qualityfactors.

Edible films and coatings may be used to preserve the quality of several food commodities.
The oxygen-barrier properties of film and coating layers can prevent oxidation of lipid ingredients, colorants and flavours of food products such as nuts, confectionary,fried products, and coloured produce.

Many climacteric fruits and vegetables can be coated with edible film-formingmaterials to slow down their respiration rate.High-fat meat and fish products, such as sausages, jerky, and fillets, can be protectedfrom oxidation after an edible coating process. Moisture-barrier properties of ediblefilms can protect fresh fruits and vegetables from dehydration. Moistureloss is the most critical quality degradation factor of fresh produce.

The moisture barrier property can also be utilized to prevent moisture migrationbetween heterogeneous food product ingredients, for example between raisins andbreakfast cereals, pie fillings and crusts and baking dough. The active ingredient carrier function is very useful for the addition of quality preserving agents as well as nutrientsand nutraceuticals, resulting in an upgraded quality level of products such as coloured or flavouredconfectionary, glazed bakery, flavoured nuts, and vitamin-enriched rice.

28.5.5 Shelf-life extension and safety enhancement

The enhancement and maintenance of quality are directly related to shelf-life extensionand safety improvement. An increased protective function of food products extends shelf life and reduces the possibility ofcontamination by foreign matter. The market for minimallyprocessed foods and fresh produce has recently seen a significant increase, and accordinglythere is a requirement to secure the safety and extend the shelf life of the products involved. The massive scale of modern food manufacturing, distribution systems, and fast-food business also dictates the need for improved systemic procedures for maintaining safety and shelf life.
The use of biodegradable materials for food packaging in the food service businessis attractive because it reduces the total amount of synthetic materials and appeals

toenvironmentally conscious consumers. However, it is obvious that the period of disintegrationof edible films and coatings through biodegradation mechanisms should be longerthan the expected shelf life of the packaged products.

28.5.6 Other process-aiding functions

Edible films and coatings can increase the effectiveness of some food processing unitoperations. For example, edible coatings on potato slices/strips or fish can reduce oilabsorption during frying. Edible coatings on fruits and vegetables can retard the oxidation of dried productsduring dehydration and improve the shelf-life extension imparted by irradiation. Edible coatings of plasticizers can also reduce the loss of colour, flavour, or nutrients in particulate fluid foods during processing and distribution. Edible coatings improve the effectiveness of the popping process ofpopcorn, and act as adhesion agents between heterogeneous food ingredients.

Many advantages may result from the osmotic dehydration of fruits, vegetables, and functional foods. Since the osmotic dehydration utilizes the migration of water caused by osmotic pressure, many other water-soluble ingredients can be released from the food into the dehydrating fluids (which are generally specific sugar solutions). Edible coatings applied prior to the osmotic dehydration can prevent the migration of valuable ingredients into the dehydrating fluids during the dehydration process, as well asminimizing the invasion of dehydrating agents into the food itself. Therefore, edible coatings can broaden the selection of dehydrating agentsand optimize operation conditions. To maximize the benefit of edible coatings for the osmotic dehydration process, the edible coating layer should have selective migration rates. Water vapour permeability should be high to enhance dehydration; however, the permeability of valuable ingredients or dehydrating agents should be very low to protect their migration during dehydration. Edible coatings on food products may be beneficial to freeze-drying processes, since the moisture-permeable coating can prevent the evaporation of volatile flavours. Evidently, extensive experimental studies are requiredto verify and validate the benefits of edible coatings as applied to food operations.

28.6 Conclusion

Edible films and coatings are promising systems for the improvement of food quality,shelf life, safety and functionality. They can be used as individual packaging materials,food coating materials, active ingredient carriers, and to separate the compartments ofheterogeneous ingredients within foods. The efficiency and functional properties ofedible film and coating materials are highly dependent on the inherent characteristicsof film-forming materials, namely biopolymers (such as proteins, carbohydrates, andlipids), plasticizers, and other additives. Most biopolymers are relatively hydrophiliccompared to commercial plastic materials. For industrial use, it is necessary to conductscientific research to identify the film-forming mechanisms of biopolymers inorder to optimize their properties. It is also suggested that feasibility studies be performedregarding the commercial uses of edible films and coatings by extending theresults of research and development studies to commercialization studies, such as newprocess evaluation, safety and toxicity determination, regulatory assessment, and consumerstudies.

11 Food Packaging

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11.1 Introduction

Food packaging is defined as a co-ordinated system of preparing food for transport, distribution, storage, retailing, and end-use to satisfy the ultimate consumer with optimal cost (Coles et al., 2003). Food packaging is an essential part of modern society; commercially processed food could not be handled and distributed safely and efficiently without packaging. The World Packaging Organization (WPO) estimates that more than 25% of food is wasted because of poor packaging (WPO, 2009). Thus, it is clear that optimal packaging can reduce the large amount of food waste. Moreover, the current consumer demand for convenient and high-quality food products has increased the impact of food packaging. The purpose of this chapter is to provide background knowledge for those who are interested in or may become involved in the development of food packaging and/or processing.

This chapter consists of four major parts. The development of quality food packaging is impossible if the packaging does not perform its required functions. Therefore, the first part of this chapter discusses the important role packaging plays in maintaining food quality and reducing product waste. The second part is about the properties and forms of food packaging materials and systems to facilitate understanding and appreciation of the major packaging materials, including plastic, paper, metal, and glass, which can affect the quality of food and its shelf life. The third part of the chapter explains aseptic packaging, modified atmosphere packaging and active packaging technologies, which have assumed increasing importance in the food industry in recent years. Finally, the last part of the chapter discusses sustainable food packaging issues, including recycling, biodegradable materials, and package design.

11.2 Functions of food packaging

11.2.1 Containment

The term "containment" means, simply, to contain products to enable them to be moved or stored. It is so basic that it is easily overlooked. However, containment is a key factor for all other packaging functions. All products must be contained for delivery from their point of production to their ultimate destination. Even items that consumers consider as "not a packaged product," such as bulk produce, must be packaged for transportation. Without packaging, products are likely to be lost or contaminated by the environment. For this reason, we have actually used packaging for millennia. Early packaging such as animal skins, baskets, or leaves from trees were used to contain liquids, powders, grains, etc. The containment function significantly contributes to protecting and preserving products during their distribution.

11.2.2 Protection/preservation

There are two broad types of damage that fresh and processed foods sustain during storage and transportation. One is physical damage such as shock, vibration, compressive forces, etc. The other is environmental damage that occurs due to exposure to water, light, gases, odors, microorganisms, etc. A good packaging system will protect or reduce these types of damage to the package contents. For example, an essential aroma or flavor in coffee or juice may easily be evaporated or oxidized without optimum barrier packaging. A shelf-stable food in a can or pouch may maintain its stability (especially against microorganisms) as long as the package provides protection. However, in the case of fresh food products, the ideal

Food Processing: Principles and Applications, Second Edition. Edited by Stephanie Clark, Stephanie Jung, and Buddhi Lamsal.

protection is usually hard to achieve with packaging alone. Since temperature is a major influence on the degradation of food, it is more economical to control temperature through supply chain modification (refrigeration, freezing, etc.). However, packaging can also add a certain level of protection to slow down temperature changes.

11.2.3 Communication

According to the Fair Packaging and Labeling Act (Federal Trade Commission, 1994), food packaging must identify the product, the net quantity of the contents, name/address of business of the manufacturer, packer, or distributor, as well as (usually) nutritional information. The communication function of packaging not only includes the information provided by the written text, but also elements of the packaging design such as package shape, color, recognized symbols or brands. Beyond giving information, the communication function is expected to entice the consumer to purchase the product. Packaging has been regarded as the "silent salesman" (Judd et al., 1989). Consumers may instantly recognize products through appetizing pictures or distinctive brands on packaging, and even simple transparency of the packaging material can attract consumers by allowing them to view the product inside (Selke, 2012).

Another aspect of the communication function is also important. The Universal Product Code (UPC) is widely used to facilitate rapid and accurate checkout in retail stores. Also, most warehouse and distribution centers track and manage their inventory using UPCs. Currently, by using radiofrequency identification (RFID) tags attached to secondary and tertiary packages, manufacturers are able to get better demand signals from customers and markets. An RFID tag can gather data on items automatically without human intervention or data entry. It identifies, categorizes, and manages product and information flow at important inspection and decision points. In addition, RFID tags can be read all at once (e.g. up to 50 per second), while UPC codes can only be read one at a time (Myerson, 2007). RFID technology looks promising in terms of revolutionizing the supply chain. However, it needs to be economical. The cost of individual tags and antenna reading systems is still high. Another problem is the lack of uniformity in global standards in the area of sensor technology. Sensor providers usually provide their own interfaces to communicate with their own tags (Lopez et al., 2011).

11.2.4 Utility

This function of packaging is sometimes termed "convenience." Consumers demand products that fit into their lifestyles and the packaging industry has had to respond to this. Thus, the utility function encompasses all the packaging attributes that provide added value and convenience to the users of the product and/or package. For example, an important social trend is the growing number of mothers in the workforce and smaller households (people living alone and married couples without children). Unquestionably, food products that offer simplification and convenience have grown in popularity with this group; examples include microwavable entrees, steam-in-pouch vegetables, oven-safe meat pouches, pump-action condiments, and so on.

11.3 Packaging systems

We can categorize packaging systems into four groups: primary packaging, secondary packaging, distribution or tertiary packaging, and unit load.

11.3.1 Primary packaging

The first-level package that directly contacts the product is referred to as the "primary package." For example, a beverage can or a jar, a paper envelope for a tea bag, an inner bag in a cereal box, and an individual candy wrap in a pouch are primary packages, and their main function is to contain and preserve the product (Soroka, 2008a). Primary packages must be non-toxic and compatible with the food and should not cause any changes in food attributes such as color changes, undesired chemical reactions, flavor, etc.

11.3.2 Secondary packaging

The secondary package contains two or more primary packages and protects the primary packages from damage during shipment and storage. Secondary packages are also used to prevent dirt and contaminants from soiling the primary packages; they also unitize groups of primary packages. A shrink wrap and a plastic ring connector that bundles two or more cans together to enhance ease of handling are examples of secondary packages.

11.3.3 Tertiary package

The tertiary package is the shipping container, which typically contains a number of the primary or secondary packages. It is also referred to as the "distribution package." A corrugated box is by far the most common form of tertiary package. Its main function is to protect the product during distribution and to provide for efficient handling.

11.3.4 Unit load

A unit load means a group of tertiary packages assembled into a single unit. If the corrugated boxes are placed on a pallet and stretch wrapped for mechanical handling, shipping and storage, the single unit is referred to as a "unit load." The objective is to aid in the automated handling of larger amounts of product. A fork-lift truck or similar equipment is used to transport the unit load.

11.3.5 Consumer/industrial packaging

Packaging systems can also be categorized into consumer and industrial packaging. Consumer packaging means a package that will be delivered to the ultimate consumer in the retail store. Usually, primary and secondary packages fit in this category. Industrial packaging means a package for warehousing and distribution to the retail store. Tertiary packages and unit loads fit in this category.

Not all package systems are actually composed of a set of primary, secondary, and tertiary packages. For example, the packaging system for potato chips usually consists only of a flexible barrier bag and a corrugated shipping container before they are palletized, while mayonnaise jars are sold in a club store as a two-pack consisting of plastic bottles, shrink wrap, corrugated boxes, and pallet. Often, the distinction between consumer and industrial packaging is more clear-cut than between primary, secondary, and tertiary packaging.

11.4 Materials for food packaging

11.4.1 Plastics

Plastics are a special group of polymers that can be formed into a wide variety of shapes using controlled heat and pressure at relatively low temperatures, compared to metals and glass. Plastics are actually a subcategory of polymers, but in packaging the terms tend to be used interchangeably. There are hundreds of identified "species" of synthetic polymers but in practice, only a few polymers are often used for food packaging. The use of plastics has increased more rapidly than any other material, and plastic is now the second most used material for packaging. Each plastic has its own unique properties, based on its chemical composition. The performance and interaction with a variety of foods are different for each material. Thus, the plastic material for the packaging of a specific food is selected to function well within the parameters of the application. This subsection focuses on the properties and applications of the plastics that are most commonly used for food packaging.

11.4.1.1 Types of plastics and general properties

11.4.1.1.1 Polyethylene (PE)

Polyethylene, polymerized from ethylene, is the plastic most commonly used for food packaging. PE generally has flexibility, good moisture control, oil and chemical resistance, and good impact strength. PE is also an inexpensive plastic, so for applications where its performance is suitable, this plastic is usually the most economical choice. The simplest form of PE is a completely unbranched structure of $-CH_2-$ units. However, some side branches are always formed during polymerization. If the branches are relatively few and short (2–4 carbon atoms), the structure can fold and pack tightly and yields high-density polyethylene (HDPE). Conversely, if there are many long branches, PE becomes low-density polyethylene (LDPE).

Low-density polyethylene is softer and more flexible, and has lower tensile strength than HDPE. Since it has relatively weak intermolecular forces, LDPE has a low melting temperature, 105–115 °C, so it is a useful material for heat sealing. LDPE also has good impact and tear strength. Common applications for LDPE include stretch wraps, shrink wraps, and many types of bags and pouches. LDPE is also used as an adhesive layer for multilayer composite structures, as a coating on paper to provide water protection (such as in milk cartons), in flexible lids for plastic tubs, in squeezable plastic tubes, in soft squeeze bottles, and in a variety of other applications. By far the majority of its use in packaging is in some form of flexible structure, and packaging is the largest market for LDPE.

Like LDPE, HDPE has good oil and grease resistance. It has better barrier properties than LDPE, since permeation occurs almost exclusively through amorphous areas of a polymer, and HDPE has less amorphous area and higher crystallinity than LDPE. It is, therefore, a good water vapor barrier. However, its barrier to oxygen and carbon dioxide, though improved over LDPE, is still very poor. The improved stiffness of HDPE makes it more suitable than LDPE for rigid or semi-rigid packaging applications, such as bottles, tubs, and trays. In particular, blow-molded bottles for food products are the largest single packaging market for HDPE.

Linear LDPE (LLDPE) is a co-polymer of ethylene and a co-monomer that has short "branches" of a uniform length, distributed randomly in the polymer molecule. The density range of LLDPE is the same as that of LDPE. Compared to LDPE of equal density, because of the structure, LLDPE typically has 50–75% higher tensile strength, 50% or greater elongation, and greater stiffness, along with improved impact strength and puncture resistance. LLDPE is more expensive than LDPE but since the superior performance allows the use of significantly less LLDPE in many applications, switching from LDPE to LLDPE often permits significant economic savings. On the other hand, LLDPE has a higher melting temperature and does not heat seal as well as LDPE so LDPE and LLDPE are often blended to get the best mix of performance and cost. New catalysts allow LLDPE to be produced with the equivalent of long-chain branches, improving its heat seal performance, but with added cost.

11.4.1.1.2 Polypropylene (PP)

Polypropylene is polymerized from propylene gas, which is a relatively low-cost feedstock like ethylene (Soroka, 2008a). As with the PE family, PP has good chemical and grease resistance. Barrier properties of PP are similar to those of HDPE; it is a good water vapor barrier but a poor gas barrier. The polypropylene structure includes methyl groups ($-CH_3$) attached to every other carbon in the polymer main chain; consequently PP has a lower density and a higher glass transition temperature (the temperature above which a plastic becomes soft and flexible) and higher melting temperature than PE. At freezing temperatures, unmodified PP is very close to its glass transition temperature, and therefore tends to have serious brittleness problems. On the other hand, PP is suitable for use with products that require moderately high temperatures such as hot filling or reheating (but not cooking) in a microwave oven.

One of the main uses of PP in food packaging is in closures (caps). Particularly for threaded caps, while HDPE is deformed too readily and loses sealing force under stress, PP maintains its original stiffness and performs successfully. PP also has outstanding living hinge properties, which is particularly useful for caps where an integral hinge is part of the design. The use of oriented polypropylene (OPP) film has increased rapidly in recent food packaging applications because a wide range of properties (such as tensile strength, shrinkage rate, transparency, etc.) can be manipulated by the orientation. OPP film has improved mechanical strength and water barrier properties compared to unoriented (cast) film. OPP film, however, is still not suited for gas barrier applications. Biaxial orientation improves clarity because the variation of crystallized layers in PP is reduced across the thickness of the film (less light refraction).

11.4.1.1.3 Polystyrene (PS)

Polystyrene is a linear addition polymer of styrene resulting in a benzene ring attached to every other carbon in the main polymer chain. It is a material that is brittle and clear and has high surface gloss. The use of PS in food packaging is aesthetically appreciated, but the material cannot generally be used when extended shelf life is required because of its poor water vapor and gas barrier properties.

The brittleness of PS limits its use where good impact resistance is required. In order to reduce the tendency to fracture, oriented polystyrene (OPS) is commonly used. Typical applications include produce and meat trays, lids for drink cups, and inexpensive party glasses.

High-impact PS (HIPS) is a PS co-polymer with polybutadiene (synthetic rubber). Adding the synthetic rubber causes HIPS to become opaque but improves the impact resistance significantly. HIPS is commonly used for disposable cutlery, tubs, and other thermoformed containers.

Polystyrene foam incorporates small bubbles within the plastic, which increase the cushioning properties and insulating ability of PS. PS foam is usually called expanded polystyrene (EPS). While it is not uncommon for this material to be called styrofoam, that name is proprietary for Dow Chemical Company's EPS building insulation and should not be used to describe a packaging material. Foamed PS is commonly used for disposable coffee cups, meat and produce trays, egg cartons, etc.

11.4.1.1.4 Polyvinyl alcohol (PVOH)/ethylene vinyl alcohol (EVOH)

Polyvinyl alcohol is produced by hydrolysis of polyvinyl acetate, PVA. Due to the hydrogen bonding (OH) group in the structure, PVOH can provide an excellent gas barrier when it is totally dry. However, PVOH is readily water soluble and loses its gas barrier properties in humid conditions, which greatly limits its usefulness for food packaging. Also, pure PVOH is difficult to process and cannot be thermoformed or extruded. PVOH is non-toxic and biodegradable once dissolved. This material is generally used in water-soluble pouches such as those for laundry or dishwasher detergent.

Ethylene vinyl alcohol (EVOH) is, in essence, a co-polymer of ethylene and vinyl alcohol. Modification with the ethylene groups decreases the water sensitivity of the material (so it no longer is soluble in water) and greatly improves its process ability. EVOH has high mechanical strength and toughness, good clarity, very high resistance to oil and organic solvents, and excellent gas barrier properties. It is the most widely used packaging plastic for an oxygen barrier. EVOH is expensive and susceptible to moisture so it is usually not used alone. Other films that provide a reasonably good water barrier are generally used to surround and protect EVOH from exposure to moisture.

11.4.1.1.5 Polyester (PET)

Polyethylene terephthalate (PET) is commonly produced by the reaction of ethylene glycol and terephthalic acid and has been one of the fastest growing food packaging plastics for the last several years. While PET is only one member of the general polyester family, the name "polyester" is generally regarded as PET, as it is the most commonly used plastic of the family. The properties of PET are attractive as a food packaging material; it has very high mechanical strength, good chemical resistance, light weight, excellent clarity, and reasonably high barrier properties. PET is also stable over a wide range of temperatures (−60 °C to 220 °C). Thus, under some circumstances PET can be used for "boil-in-the-bag" products which are stored frozen before reheating or in dual-ovenable containers, since it has resistance to higher temperatures than many other plastics. PET is mostly oriented biaxially to improve its mechanical strength and gas barrier properties.

Polyethylene terephthalate recently took over from HDPE as the most widely used plastic in bottles of all types (HDPE still predominates in the overall container category). Its first large-scale use was in bottles for carbonated soft drinks. Its barrier properties and mechanical strength are much higher than those of HDPE, with excellent transparency. It is more expensive than HDPE but offers improved performance, and its cost has decreased as production has increased.

One disadvantage of PET is its low melt strength (the ability to maintain its general shape in molten status). PET flows like a liquid (rather than like a viscous plastic) at its melting temperature, and has a narrow melting temperature range. These characteristics make forming and sealing difficult. Thus, careful control of processing temperatures is important for PET. In order to increase the melt strength of PET, PET co-polymers can be used. The most widely used co-polymer is glycol-modified PET (PETG). This has greatly reduced crystallinity and reasonably good melt strength, which allows it to be thermoformed or extrusion blow molded into clear bottles.

11.4.1.1.6 Polyvinyl chloride (PVC)

Polyvinyl chloride is produced from vinyl chloride monomers. PVC has high toughness and strength, good dimensional stability, good clarity, excellent oil barrier properties, and good heat sealability. Even though it has many beneficial properties, PVC is easily degraded at high temperature. It decomposes and gives off hydrogen chloride (HCl) around its melting temperature. Thus, unmodified PVC is almost impossible to process due to thermal degradation. Most PVC used in packaging is mixed with a large amount of plasticizer to decrease its melting point and hence reduce thermal degradation. Since the incorporation of plasticizer reduces the attractions between neighboring polymer molecules and reduces the melting point, it also has significant impacts on all the material's properties. For example, highly plasticized PVC films have excellent stretch properties and unique "cling," making them ideal for hand wrapping fresh meats, but the films have poor barrier properties. One of the most widespread uses of PVC is in various blister packages (e.g. medical tablets, toothbrushes, etc.) and clamshells (e.g. USB memory cards, batteries, etc.). Due to the ease of thermoforming, excellent transparency, and relatively low cost, PVC is an attractive material for these types of packages.

The high plasticizer content and the presence of residual vinyl chloride monomer have been a concern for use of PVC as a food packaging material. The levels of vinyl chloride monomer (VCM) in PVC food packaging are currently extremely low. The Food and Drug Administration (FDA) proposed limiting the VCM level to between 5 and 10 parts per billion (ppb) (FDA, 2002). So far, no evidence has been presented that PVC itself is a carcinogen, though VCM is known to be one. However, in recent years, many PVC packages, such as water and vegetable oil bottles, have been replaced by PET. PET is rapidly replacing PVC in thermoformed blister packages and clamshells for food products, as well. However, PVC film is still widely used for the stretch wrapping of trays containing fresh red meat and produce.

11.4.1.1.7 Polyvinylidene chloride (PVDC)

Polyvinylidene chloride has one more chlorine atom per monomer unit than PVC. Like PVC, PVDC is also a very heat-sensitive material. It is decomposed and generates HCl at only a few degrees above its melting temperature. PVDC can be modified with various co-monomers, typically in amounts between 6% and 28%. Properties of PVDC depend on the type as well as the amount of the co-monomer. The most noticeable benefit of this plastic is its excellent barrier properties against water vapor, odors/flavors, and gases. Thus, PVDC plastic is commonly used in food and pharmaceuticals as a barrier packaging material. Since it is a relatively expensive material, PVDC is rarely used alone in packaging containers. It is usually used as a component in multilayer structures or applied as a coating layer. One common use of PVDC coating is as a combination oxygen and moisture barrier and heat-seal layer on cellophane. PVDC is also used in co-extruded structures such as plastic cans, for its excellent barrier properties. PVDC co-polymer film is frequently used as a household wrap or a shrink film.

11.4.1.1.8 Polyamides (PA or nylon)

Nylons, or polyamides (PA), are a whole family of synthetic polymers. The term "nylon," formerly a DuPont trade name, is more frequently used in the US. It is formed by condensation polymerization of a diamine and a dibasic acid or by polymerization of certain amino acids. Various chemical structures can be produced but the amide (–CONH–) functional group is always present in the main structure and is largely responsible for the mechanical strength and barrier properties.

Based on their polymerization method, two categories of PA can be identified. One family is made by polymerizing a mixture of diamines and diacids. These can be named using the number of carbons in the straight-chain diacids and straight-chain diamines they are made from. Thus nylon 6,6 is formed from a 6-carbon amine plus a 6-carbon acid. The other family of PAs is formed from only one type of monomer, an amino acid, and is identified by the number of carbons in that amino acid. Nylon 6, for example, is formed from a 6-carbon amino acid. These two types of PA have similar physical and chemical properties. The number of carbons in the structure affects the properties of PA. Longer carbon chains (more CH_2 groups) result in plastics with a lower melting point and increased resistance to water vapor.

A semi-crystalline polyamide, MXD6, was introduced in the 1980s. It is formed by condensing metaxylene diamine and adipic acid (a straight-chain 6-carbon carboxylic acid). MXD6 provides much higher water barrier properties than conventional PAs.

Polyamides in general provide excellent optical clarity, oil and chemical resistance, and mechanical strength over a wide range of temperatures. In packaging applications, the use of PA is often found in the form of film for high-temperature sterilization or hot-filling applications. PAs also act as flavor and gas barriers, but have poor water vapor barrier properties. Thus, for most applications PAs are combined with other materials, such as LDPE and ionomer, to add water vapor barrier and heat sealability properties. These types of materials are used in the vacuum packaging of meats and cheeses.

11.4.1.1.9 Polycarbonate (PC)

Polycarbonate is made from carbonic acid and bisphenol A. The proper name for PC is polybisphenol-A carbonate (as is the case for "polyester," the generic name has come to mean this most used member of the family). The material is a very tough and rigid plastic with excellent clarity. However, it has a relatively high permeability to both water vapor and gases. Thus, it must be coated if good barrier properties are required. Its main packaging uses are large refillable water bottles and refillable milk jugs. PC is also used to a very limited extent in food packaging as a component of multilayer structures to provide transparency and in high strength containers (with high barrier materials). For example, multilayer beer or beverage bottles, containing PC and a thin barrier layer such as EVOH or PVDC, can be used to extend shelf life while still providing transparency (Hernandez, 1997). However, the application is limited by the relatively high cost of PC.

11.4.1.1.10 Ionomers

Ionomers have an unusual structure compared to other plastics. These plastics contain ionic as well as covalent bonds, while other packaging plastics have only covalent bonds in their structure. The plastic is manufactured by neutralization of ethylene-based co-polymers containing acid groups with a base containing a metal (such as sodium, zinc, lithium, etc.). The result is positively charged metal ions and negatively charged ions in the base polymer chain, creating random cross-link like ionic bonds between the polymer chains. This combination of ionic and covalent bonds creates a polymer with excellent toughness as well as transparency. Ionomers also have excellent adhesion properties so they are commonly used in composite structures with film, paper, or aluminum foil to provide an inner layer with excellent heat sealability. They are especially useful in applications where the sealing layer may become contaminated, making it difficult to provide strong heat seals, such as in packaging of processed meats. The excellent impact and puncture resistance of ionomers, even at low temperatures, is also useful for skin packaging of sharp items such as meat cuts containing bone (as well as for inherently sharp products such as knives). Another advantage is ionomers' high infrared absorption, which allows faster heat shrink packaging processes. On the other hand, ionomers are relatively high-cost materials and have relatively poor gas barrier properties.

11.4.1.2 Additives

Additives are auxiliary ingredients intended to modify or enhance a plastic's properties without recognizably changing its chemical structure. Nearly all commercial resins are blended with additives before or during processing into their finished forms. In food packaging, all additives used must comply with the regulations of the appropriate food regulatory authority. For example, the maximum allowable migration of an additive from a packaging material is generally controlled by FDA regulations (FDA, 2005a).

Stabilizers are one of the most common ingredients in plastic resins. Plastics are susceptible to chemical changes during processing, as a result of their exposure to heat, mechanical force (shear), and usually oxygen. Stabilizers minimize the thermal oxidation or other reactions undergone by the polymer.

Plasticizers perform a lubricating function within the plastic material and make it more flexible. They also lower the glass transition and melting temperatures (as discussed in sections 11.4.1.1.6 and 11.4.1.1.7).

Colorants alter the color of plastic materials. Usually pigments (or sometimes dyes) are blended into the plastic as master batch color concentrates at the forming machine. It is possible to obtain virtually any desired color from most plastics, with the appropriate selection of colorants.

Nucleating agents encourage the formation of crystallinity in the polymer. The agents are often used to improve the clarity of PP. By adding a nucleating agent, the crystallite size in the PP can be minimized without any overall decrease in crystallinity, resulting in improved clarity without loss of other performance properties.

There are also additives designed to modify the surface of the plastic. These include slip agents, antislip agents, antiblocking agents, lubricants, mold release agents, antifogging agents, and antistatic agents.

11.4.1.3 Processing and converting of plastics

11.4.1.3.1 Extrusion

Most plastic forming processes begin with melting the plastic in an extruder, except for compression molding and solvent casting techniques. In the extruder, thermoplastics are mixed and softened, which enables shaping into some desired form when they reach an optimum temperature and pressure. Extrusion is used to convert plastic resin into a sheet, film, or tube. There are two main sources of the heat that melts the plastic resin. One is external heating, usually electric heater bands, and the other is friction within the extruder, as the plastic is conveyed. When the melted plastic exits the extruder, it is sent through a die of a desired shape.

In order to convert the molten plastic into film, two processes are commonly used: the cast film process (also called the flat film process) and the blown film process (also called the tubular process). For cast film, the molten plastic is extruded through a slit die, and then it is cooled on a chilled roller (or sometimes in a quenching water bath), as shown in Figure 11.1. Due to the rapid cooling, cast film generally has better clarity than blown film, and the process also results in more uniform thickness. For blown film, the molten plastic is extruded though an annular die. The plastic exits the extruder in the shape of a hollow tube, which is expanded with internal air pressure. As is shown in Figure 11.2, the film is stretched in the longitudinal and circumferential directions during the process which results in biaxial orientation of the film. The blown film process is usually more economical than the cast film process for long runs, and the mechanical

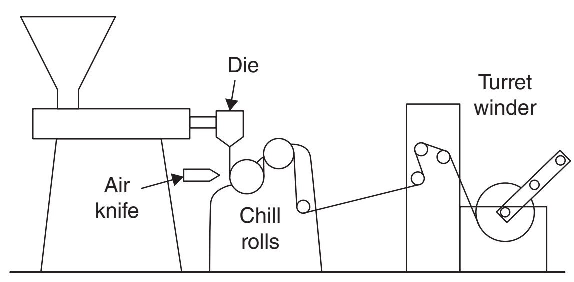

Figure 11.1 Cast film process (from Selke et al., 2004).

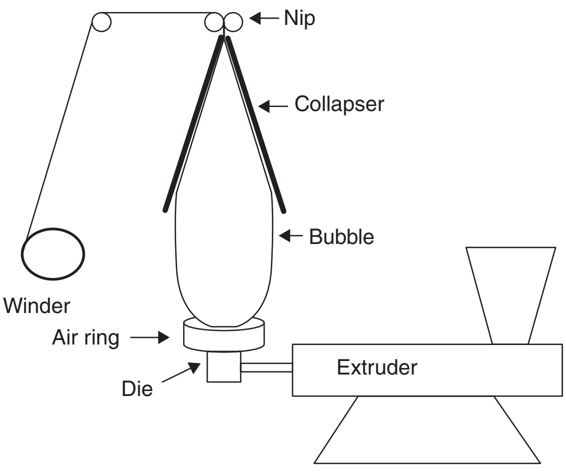

Figure 11.2 Blown film process (from Selke et al., 2004).

properties are often better than cast film, due to the biaxial orientation. Plastic resins for the blown film process must have good melt strength. Thus, not all polymer films can be produced by the blown film process. Blown film tends to have more variation in thickness and less clarity than cast film. Most plastic bags are made using the blown film process.

11.4.1.3.2 Thermoforming

In thermoforming, a plastic sheet heated to its optimum temperature (near its melting temperature) is placed over a mold, and pressure is applied to stretch it into a designed shape. The forming pressure (the pressure used to stretch the sheet) is obtained by pneumatic and/or mechanical means. In the simplest system, a vacuum is drawn through the mold and the forming pressure comes simply from atmospheric pressure pushing the plastic into the mold. In order to get good results from thermoforming, it is best if the plastic sheet is relatively easy to form and the molded shape is relatively simple. Typical thermoplastics used for thermoforming include HIPS, PVC, PP, PA, and PET. Packages made by thermoforming include clamshells, blister packages, and some tubs.

11.4.1.3.3 Injection molding

In an injection molding operation, the molten plastic (from the extruder) is injected into a mold with the desired shape, cooled, and ejected from the mold. Injection molding is widely used for making threaded closures (caps), tubs, and jars, and for making the initial shapes (preforms) used for injection blow-molded bottles. Injection molding can provide accurate and sophisticated forms as well as a high production rate. However, it is a relatively expensive process and short production runs are not economical. Resins that are commonly used for injection molding include LDPE, HDPE, PP, and PET.

11.4.1.3.4 Blow molding

In the blow molding process, an initial shape (called a parison) is surrounded by a mold with the desired shape, and air is blown into the parison to force it to expand against the wall of the mold. The mold is then opened and the solidified product is ejected. There are two major categories of blow molding: extrusion blow molding and injection blow molding.

Extrusion blow molding is the most used blow molding process. The parison is continuously extruded as a hollow tube. When the parison reaches the proper length, the open halves of the mold are closed around the parison. This tube is usually extruded in a downward direction, and air pressure inflates the hollow tube into the shape of the container. The tubular parison is cut off at the top and pinched shut at the bottom before blowing. Thus, all containers produced by extrusion blow molding have a pinch-off line across the bottom and mold parting lines on the sides. This is a fast and inexpensive process. Extrusion blow molding is commonly used for HDPE 1/2 gallon and 1 gallon milk and water bottles where high barrier properties (against gas and flavors) are not required. The plastic for extrusion blow molding must have sufficient melt strength to maintain that hollow tube shape and permit it to be formed further. Another limitation is rather limited control over the distribution of wall thickness.

Injection blow molding starts with injection molding of a preform. The preform usually has a test tube-like shape and is nearly the same length as the height of the bottle. After injection molding, the hot preform is placed into the container mold and air pressure is used to stretch it into the mold shape. Sometimes, the preform is produced earlier, cooled, and then reheated before the blowing process. After cooling, the mold is opened and the finished container is ejected. This process provides better dimensional accuracy, including uniform wall thickness and a high-quality neck finish (threaded area). Another advantage of this process is that it produces less scrap than extrusion blow molding.

Injection stretch blow molding is similar to injection blow molding but the length of the preform is considerably shorter than the height of the bottle. During the blow molding process, the preform is stretched in both the longitudinal and transverse directions, so the container is biaxially oriented. The finished product has better mechanical strength, better gas and water vapor barrier properties, and better transparency due to the orientation. Careful control over the temperature profile in the parison is extremely important for successful stretch blow molding. Injection stretch blow molding is used to produce PET bottles for carbonated beverages, sports drinks, juices or other bottles, including those used in hot-fill and aseptic processing.

11.4.1.4 Plastic permeability

While glass and metal have almost perfect barrier properties, plastics are permeable in various degrees to gases, water vapor, organic vapors, or other low molecular weight compounds. When the gas or vapor compounds pass through the plastic, they must solubilize at first, diffuse through the material, and finally desorb on the other side. Such vapor or gas mass transfer (or permeability) has a significant impact on the shelf life, quality, and safety of foods. For example, the expected loss of moisture from juice or of CO_2 from carbonated beverages, depending on storage conditions, can be estimated through quantitative evaluation of the package permeability. Similarly, the time required to reach certain atmospheric conditions in the package that favor the growth of aerobic or anaerobic pathogens can also be estimated through calculation of the permeability. These are just two of many examples that could be cited. This section only provides a general theoretical background for permeability and discussion of factors affecting the permeability of gases/vapors through materials.

11.4.1.4.1 Basic theory of permeability

Under steady-state conditions, the permeability coefficient of a non-porous plastic is described by the following equation (Crank, 1975):

$$P = D \times S \tag{11.1}$$

where P is the permeability coefficient, D is the diffusion coefficient, which is a measure of how fast the permeant compounds are moving through the plastic polymer, and S is the solubility coefficient that shows how much permeant is contained within the plastic.

Calculation of permeability of plastics is based on Fick's first law of diffusion. A gas or vapor will diffuse through a plastic film at a constant rate if a constant pressure difference is maintained across the plastic:

$$F = -D\frac{\partial c}{\partial x} \tag{11.2}$$

where F is the flux (vapor mass transfer), D is the diffusion coefficient, c is concentration of permeant in the plastic and x is the distance across the plastic (or thickness). If the flow and diffusion rate are constant, the above equation gives the following equation:

$$F = -D\frac{c_2 - c_1}{L} \tag{11.3}$$

where c_1 and c_2 are the concentrations of the diffusing compound on the two sides of the plastic film. L refers to the thickness of the film. The flux (F) can be defined as the amount of permeant (Q) passing through a surface of unit area (A) in time (t). Thus, the above equation can be rewritten as follows:

$$F = \frac{Q}{At} \tag{11.4}$$

$$Q = D\frac{(c_1 - c_2)At}{L} \tag{11.5}$$

In the case of gas permeation, it is easier to measure the equilibrium vapor pressure (p) rather than the actual concentrations of the permeant in the film. Using Henry's law, the concentrations of the permeants (c) can be expressed as:

$$c = S\,p \tag{11.6}$$

where p is the partial pressure and S is the solubility coefficient. Then, by combining Equations 11.5 and 11.6, the following equation is formed:

$$Q = DS\frac{(p_1 - p_2)At}{L} \tag{11.7}$$

The DS can be replaced with P, the permeability coefficient, based on Equation 11.1. Finally, the permeability coefficient (P) can be rewritten as:

$$P = \frac{QL}{At(p_1 - p_2)} \quad \text{or} \quad \frac{QL}{At\Delta p} \tag{11.8}$$

The permeation of compounds through a plastic is described by a diffusing model, using Henry's and Fick's

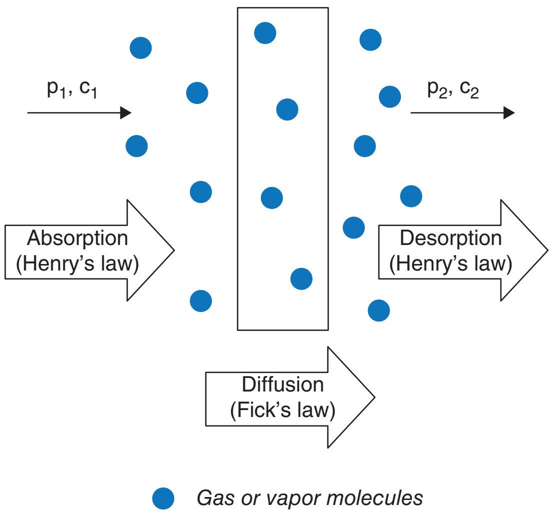

Figure 11.3 General mechanism of mass permeation through a plastic film.

laws to obtain the expression above. The mechanism is shown in Figure 11.3.

The permeability coefficient (P) can be used to estimate the shelf life of a product or to determine an appropriate package to provide the desired shelf life. There are various units available to express P. In the SI system, common units for P are:

$$P = \frac{\text{Quantity of permeant} \times \text{thickness}}{\text{area} \times \text{time} \times \text{partial vapor pressure}} = \frac{\text{cm}^3 \times \text{cm}}{\text{cm}^2 \times \text{s} \times \text{Pa}}$$

Instead of the permeability coefficient, the quantity of permeant flowing per unit area per unit time, such as the oxygen transmission rate (OTR) or water vapor transmission rate (WVTR), is frequently used to express the barrier characteristics of plastic materials. For example, OTR is related to P as follows:

$$P = \frac{QL}{At\Delta p} = \text{OTR}\frac{L}{\Delta p} \tag{11.9}$$

Example 11.1 The oxygen transmission rate of PET film with 0.1 cm thickness is 0.41 $\text{cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$. The partial pressure difference (Δp) through the film is 21278 Pa. What is the oxygen permeability coefficient of the film?

Using Equation 11.9:

$$\text{OTR}\frac{L}{\Delta p} = \frac{0.41\,\text{cm}^3}{\text{cm}^2 \times \text{s}} \times \frac{0.1\,\text{cm}}{21278\,\text{Pa}}$$
$$= 1.926 \times 10^{-6}\,\text{cm}^3 \cdot \text{cm} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$$

Example 11.2 A food stored in a PET jar with a wall thickness of 0.1 cm and a surface area of 400 cm^2 becomes rancid if it absorbs 3 cm^3 of oxygen. The O_2 permeability coefficient of PET is 1.2×10^{-15} $\text{cm}^3 \cdot \text{cm} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{pa}^{-1}$. The oxygen vapor pressure inside the container (Pi) was 0 Pa and outside the container (Po) was 21278 Pa. What is the shelf life of this product?

Using Equation 11.9:

$$P = \frac{QL}{At\Delta p}$$

The t in Equation 11.9 is the shelf life of the product if Q is the maximum allowable amount of gas inside the package. Thus, the expression can be rewritten as:

$$t = \frac{QL}{AP\Delta p}$$

$$= \frac{3\,(\text{cm}^3) \times 0.1\,(\text{cm})}{400\,(\text{cm}^2) \times 1.2 \times 10^{-15}\,(\text{cm}^3 \cdot \text{cm} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{pa}^{-1}) \times 21278(\text{pa})}$$
$$= 29373061\,\text{s} = 400\,\text{day}$$

Thus, the shelf life of the product in the PET package is 400 days.

11.4.2 Paper and paper-based materials

Paper and paperboard are the most commonly used packaging materials in the world. In the US, over 50% of all packaging is paper based, including food packaging. Paper is produced from plant fibers. More than 95% of paper is made from wood, and the remaining sources are mainly agricultural by-products, such as straw (of wheat, rye, barley, and rice), sugar cane bagasse, cotton, flax, bamboo, corn husks, and so on. Making pulp is the initial stage in making paper or paperboard, and the quality of the paper is closely related to the quality of the pulp. Pulping can be done using mechanical, chemical, or a combination process. Mechanical pulping produces papers that are characterized by relatively high bulk and low strength as well as relatively low cost. Their use in packaging is very limited. Chemical pulping produces stronger and higher quality paper and is also more expensive. Combination processes are intermediate in cost and properties. The pulp produced may be unbleached or bleached to various degrees, and various sizing agents and other additives are used to control functions and appearance.

11.4.2.1 Types of paper and their applications

Different varieties of papers are used in packaging applications. This section will give a brief overview of the major type of papers used for food packaging.

11.4.2.1.1 Kraft paper

Kraft paper is the most used packaging paper and has excellent strength. It is made using the sulfate (kraft) chemical pulping process, and is usually produced from soft wood. Unbleached kraft is the strongest and most economical type of paper. It is used in uncoated form for bags and in the production of corrugated board for boxes, as well as for drums, cans, and other applications. It can be coated or laminated for improved barrier properties and additional strength, or creped for cushioning.

11.4.2.1.2 Bleached paper

Bleached paper is produced using bleached pulps that are relatively white, bright, and soft. Its whiteness enhances print quality and aesthetic appeal. It is generally more expensive and weaker than unbleached paper. This type of paper is used uncoated for fancy bags, envelopes, and labels. However, it is often clay coated for overwraps and labels.

11.4.2.1.3 Greaseproof and glassine

Greaseproof is a dense, opaque, non-porous paper made from highly refined bleached kraft pulp. The prolonged beating during processing results in short fibers. Glassine derives its name from its glassy smooth surface. After the initial paper making process, it is passed through an additional set of calendars (supercalendared) in the presence of steam. The result is a glossy, transparent sheet with good grease and oil resistance (it does not have complete oil barrier but is still fairly resistant to oil). These papers are often used for packaging butter and other fatty foods.

11.4.2.1.4 Waxed paper

Waxed paper is produced by adding paraffin wax to one or both sides of the paper during drying. Many base papers are suitable for waxing, including greaseproof and glassine. The major types are dry waxed, wet waxed, and wax laminated. Dry-waxed paper is produced using a heated roller to allow the wax to soak into the paper. The paper does not have a waxy feel and does not have a continuous wax film on the surface. Wet-waxed paper is produced when the wax is cooled quickly after it is applied, so that the wax remains on the surface of the paper. Wax-laminated paper is bonded with a continuous film of wax which acts as an adhesive, so that it can provide both moisture barrier and a heat-sealable layer.

11.4.2.1.5 Vegetable parchment

Vegetable parchment is produced by adding concentrated sulfuric acid to the surface of the paper to swell and partially dissolve the cellulose fibers. It produces a grease-resistant paper with good wet strength (meaning that it maintains its strength well when it is wet). Vegetable parchment is odorless, tasteless, boilable, and has a fiber-free surface. Labels and inserts on products with high oil or grease content are frequently made from parchment. Parchment can also be treated with mold inhibitors and used to wrap foods such as cheese (Robertson, 2007).

11.4.2.2 Paperboards and their applications

Paper and paperboard can be distinguished by thickness (caliper) and weight of the material. Material is generally termed "paperboard" when its thickness is more than 300 μm and/or its weight exceeds 250 g/m^{-2} (Hanlon et al., 1998). Various types of paperboard are manufactured but paperboard for food packaging generally includes whiteboard, linerboard, foodboard, cartonboard, chipboard, and corrugated board.

11.4.2.2.1 Whiteboard

Whiteboard is made with a bleached pulp liner on one or both sides to improve appearance and printability, and the remaining part is filled with low-grade mechanical pulp. Whiteboard is suitable for contact with food and is often coated with polyethylene or wax for heat sealability. It is used for ice cream, chocolate, and frozen food cartons.

11.4.2.2.2 Linerboard

Linerboard is usually made from softwood kraft paper and is used for the solid faces of corrugated board. Linerboard may have multiple plies. Increasingly, linerboards containing recycled fiber are being used in packaging. The higher quality layer is always placed on top.

11.4.2.2.3 Foodboard

Foodboard is used to produce cartons that are suitable for direct food contact. It is normally made using 100% virgin pulp but recently recycled pulp using an innovative barrier coating with a sustainable coating material is also being used. Foodboard is a sanitary, coated, and water-resistant paperboard. It should be designed to protect against migration of outside contaminants (such as ink or oil) into packaged food. Foodboard can be used for all types of foods, particularly frozen and baked foods.

11.4.2.2.4 Cartonboard (boxboard)

Cartonboard is used to make folding cartons and other types of boxes. Most often, this is a multilayer material made of more than one type of pulp, and often incorporating recycled fibers. To improve its appearance, it may be clay coated or may have a ply of virgin fibers on one or both surfaces.

11.4.2.2.5 Chipboard

Chipboard is the lowest quality and lowest cost paperboard, made from 100% recycled fiber, and is not used in direct contact with foods. Outer cartons for tea and breakfast cereals are some examples. It is also commonly lined with whiteboard to produce a multi-ply board such as cartonboard.

11.4.2.2.6 Corrugated board

Corrugated board has an outer and inner lining of kraft paper with a central corrugating (fluted) material. Corrugated boards resist impact, abrasion, and compression forces so they are commonly used in shipping containers.

11.4.2.3 Paperboard cartons and other containers for food packaging

Folding cartons are made of paperboard, typically between 300 and 1100 μm in thickness. They are creased, scored, cut, and folded into the desired shape. The cartons usually are shipped flat to the product manufacturer (or carton assembler). Paperboard can be coated or laminated when improved function is desired. For example, wax lamination provides moisture resistance, glassine lamination provides oil/grease resistance, and PE lamination provides heat sealing and moisture resistance. Clay and mineral coatings on the exterior provide improved appearance and printing quality.

Molded pulp containers are produced by placing aqueous slurry of cellulosic fibers into a screened mold. Since molded pulp containers are regarded as a sustainable packaging material, they are gaining popularity. Typical applications in food packaging include egg cartons, food trays, and other tray type containers for fruits. Molded pulp containers can be laminated with thermally resistant plastics such as PET to provide functionality as dual-ovenable containers (suitable for use in conventional ovens as well as microwaves).

11.4.3 Metals

11.4.3.1 Types of metal and general properties

Metal is used in packaging in a variety of applications, from rack systems to tuna cans. For food packaging, four types of metal are commonly used: steel, aluminum, tin, and chromium.

Steel and aluminum are commonly used in production of food cans, and are the primary materials for metal packaging. Food cans are most often made of steel, and beverage cans are usually produced from aluminum. Steel tends to oxidize when it is exposed to moisture and oxygen, producing rust. Therefore, tin and chromium are used as protective layers for steel. Tinplate is a composite of tin and steel made by electrolytic coating of bare steel with a thin layer of tin to minimize corrosion. If chromium is used to provide corrosion protection instead of tin, the resulting material is called electrolytic chromium-coated steel (ECCS) or tin-free steel (TFS). ECCS is less resistant to corrosion than tinplate but has better heat resistance and is less expensive.

11.4.3.2 Can forming process

There are two basic styles of cans: three-piece and two-piece. As the name indicates, a three-piece can is made from three pieces (a body blank and two ends), and a two-piece can is made from two pieces (one body and one end).

11.4.3.2.1 Three-piece cans

Hermetically sealed three-piece cans consist of a can body and two endpieces. The process for making three-piece cans starts with rolling steel into a rectangular strip (about 1.8 mm thick). Next, coating is applied, depending on the requirements of the food. Generally, more acidic food has a higher coating weight on the inner side of the strip. Additional coating is applied to improve the surface brightness, to resist corrosion, and to prevent interaction with foods. More details about coating are provided in section 11.4.3.4. In order to make the can body, the steel sheet is cut into a rectangular piece and formed into a cylindrical shape, and its side is seamed. For food packaging, most three-piece cans are made using welded side seams. Soldering was the original method, but has been mostly discontinued due to concerns about lead contamination. Lead solder is no longer permitted for packaging of products sold in the US as well as in many other countries. Next, the body is flanged, and one end of the can is attached using a double seaming process. The double seam forms a hermetic seal by interlocking the end cover and body of the can with a rubbery sealing compound between them. After filling, the second end is attached in the same manner. The structure and main components of a double seam are shown in Figure 11.4.

Cans for food packaging are often subjected to external and internal pressure during processing and storage. The can body may be rippled or beaded to increase its strength.

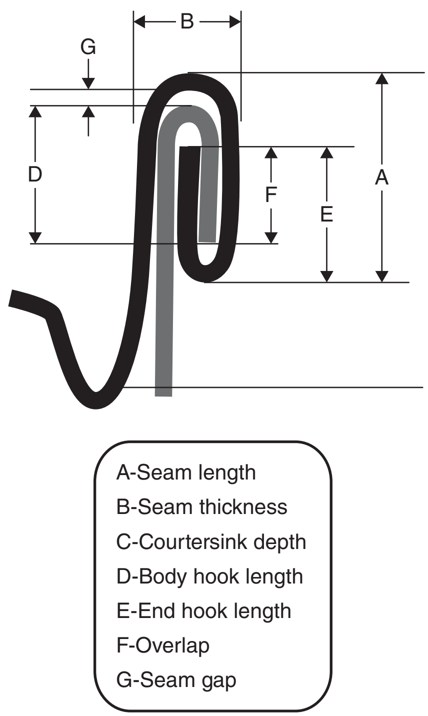

Figure 11.4 Structure and main components for double seaming.

11.4.3.2.2 Two-piece can

A two-piece can does not have a side seam. It is composed of the body and one cover for the top. There are two main methods of producing two-piece cans: draw and iron (DI) and draw and redraw (DRD). In the DRD process, a metal blank is punched into a die (drawn) to form a shallow can shape. The diameter of the cup produced in the initial draw is then further reduced by a similar redraw process. Some very short cans do not require this second draw so are not really DRD cans – these are referred to as shallow draw cans. The wall and base thickness, as well as the surface area, are the same as those of the original blank. The DRD process is commonly used for TFS cans. After the body is shaped, the can is trimmed, often beaded, and after filling the end is double seamed onto the can body.

In the DI process, typical for aluminum beverage cans, a circular disk shape blank is cut and drawn to a shallow cup. The cup is usually redrawn once, and then is passed through a series of ironing dies that extend and thin the walls. Thus, the base of the can ends up thicker than the walls. DI cans are usually used for carbonated beverages. The ends of DI cans are often necked (narrowed) to reduce the size of the end, as this improves the ability to stack the cans, and lowers the overall cost (by saving metal).

11.4.3.3 Metal foil and containers

Aluminum foil is the most commonly produced metal foil. It is manufactured by passing aluminum sheet between a series of rollers under pressure. Pure aluminum (purity >99.4%) is passed through rollers to reduce the thickness to less than 150 μm and then annealed to provide dead-folding properties. Foil is widely used for wraps (9 μm), bottle caps (50 μm), and trays for ready-to-eat meals (50–100 μm). Aluminum foil has excellent barrier properties against gases and water vapor. Thus, it is also used as the barrier material in laminated films for packages, such as those in retort pouches.

Collapsible aluminum tubes can be used for the packaging of viscous products. The collapsible tube allows the user to apply precise amounts of the products when required because the tubes permanently collapse as they are squeezed and prevent air being drawn into the container again. These types of tube applications for foods are rare in the US but more common in Europe. Typical applications include condiments packages such as mustard, mayonnaise, and ketchup.

Metallized films are also used in food packaging applications for their excellent barrier properties. The principle of metallization is to use a vapor deposition process to deposit an extremely thin layer of metal on another substrate (film). The typical thickness of the aluminum layer in metallized film is 400–500 Å. Oriented polypropylene (OPP) is the material most often used for metallized film applications. Nylon and PET are also common film substrates.

11.4.3.4 Coating

One of the major problems associated with metal packaging is corrosion. The inside of a can is normally coated to prevent interaction between the can and its contents. The outside of a can is generally also coated to provide protection from the environment. Coatings used in cans need to provide an inert barrier (must not impart flavor to the product), must usually resist physical deformation during fabrication, be flexible, spread evenly and completely cover the surface of the metal, and the coating must adhere well to the metal and be non-toxic (for food packaging).

Two methods are used for the application of protective coatings to metal containers: roller coating and spraying. The roller coating process is used for external coating of cylindrical can bodies and spraying is used if physical contact is difficult, such as for the inside surface of can bodies. Typical can coatings are polymers applied in a liquid state and then dried after application by solvent removal, oxidation or heat-induced polymerization. The commonly used coating materials for food packaging include the following (Robertson, 2007).

- **Epoxy-phenolic compounds**: these are used for all types of steel and cans. They are resistant to acids and have good heat resistance and flexibility. They are used for beer, soft drinks, meat, fish, fruits, vegetables, and so on. They are especially suitable for acidic products and have excellent properties as a basecoat under acrylic and vinyl enamels.
- **Vinyl compounds**: vinyl compounds have good adhesion and flexibility, and are resistant to acid and alkaline products. However, they are not suitable for high-temperature processes such as retorting of food. They are used for canned beers, wines, fruit juices and carbonated beverages and as clear exterior coatings.
- **Phenolic lacquers**: phenolic compounds are inexpensive and resistant to acid and sulfide compounds. They are used for acid fruits, fish, meats, soups, and vegetables.
- **Polybutadiene lacquers**: polybutadiene compounds have good adhesion, chemical resistance, and high heat resistance. They are used for beer and soft drinks, soups, and vegetables (if zinc oxide is added to the coating).
- **Acrylic lacquers**: acrylic lacquers are expensive coating materials. They take heat processing well and provide an excellent white coat. They are used both internally and externally for fruits and vegetables.
- **Epoxy amine lacquers**: epoxy amine lacquers are also expensive. They have excellent adhesion, heat and abrasion resistance, and flexibility, and no off-flavor. They are used for beer and soft drinks, dairy products, and fish.
- **Alkyd lacquers**: alkyd lacquers are low cost and used mostly as an exterior varnish over inks (due to flavor and color problems inside the can).

11.4.4 Glass

Glass is defined as “an amorphous inorganic product of fusion that has been cooled to a rigid condition without crystallizing” (ASTM, 2003). For food packaging, bottles or jars are the types of glass packaging most often used, bottles being the primary use. In the US, 75% of all glass food containers are bottles.

Glass is made primarily of silica, derived from sand or sandstone. For most glass, silica is combined with other raw materials in various proportions. For example, soda-lime glass, the glass typically used for food packaging, contains silica (68–73%), limestone (10–13%), soda ash (12–15%), and alumina (1.5–2%). Glass is inert to a wide variety of food and non-food products, very rigid and strong against pressure, transparent, and non-permeable (excellent barrier properties). However, glass has disadvantages due to its heavy weight and fragility. For food packaging, the fragility has caused some safety concerns such as the possibility of the presence of chipped glass in food products. Glass for food packaging has declined over the last three decades, with glass losing market share to metal cans and, increasingly, to plastics. However, it still plays an important role in packaging.

11.4.4.1 Forming of glass

The glass making process begins with weighing out and mixing of the raw materials and introduction of the raw material to the glass melting furnace, which is maintained at approximately 1500 °C. Cullet, broken or recycled glass, is also an important ingredient in glass production. In the melting furnace, the solid materials are converted to liquid, homogenized, and refined (getting the bubbles out). At the end of the furnace, a lump of molten glass, called a “gob,” is transferred to the glass forming process.

For food packaging, glass can be formed using the blow-and-blow process, wide-mouth-press-and-blow process, or narrow-neck-press-and-blow process. In the blow-and-blow process, compressed air blows the gob into the blank mold of the forming machine and creates the shape of the parison. Then, the completed parison is transferred into the blow mold where air blows the parison to form a final shape. In the wide-mouth-press-and-blow process, a metal plunger is used to form the gob into the parison shape, instead of using air blowing. As in the blow-and-blow process, the compressed air blows the container into its final shape. In the narrow-neck-press-and-blow process, the overall process is similar to the wide-mouth-press but a much smaller metal plunger is used to make the parison shape. Less than 38 mm of finish diameter is regarded as narrow mouth and over 38 mm is called wide mouth. (Glass Packaging Institute, 2012). The press-and-blow process provides increased productivity, less weight, and more uniform wall thickness compared to the blow-and-blow process. Beer or beverage bottles are common applications for the narrow-neck-press-and-blow process.

Once the finished container is formed, it is transferred to a large oven known as a lehr for the annealing process. The function of annealing is to reheat and gradually cool the container in order to relieve the residual thermal stress. Surface coatings are often applied to the glass container for strengthening and lubricating the surface. Hot-end coatings are applied before the container enters the annealing oven (when the glass is still hot due to the previous forming process). Hot end coatings consist of tin chloride (which reacts to form tin oxide) or organo-tin. These compounds are applied in vapor form and leave a rough high-friction surface on the glass container, which provides a good adhesive surface for the cold-end coatings. They also supply hardness, fill in minor cracks, and compress the glass surface. After the glass containers are cooled, a cold-end coating is applied to increase lubricity and minimize the scratching of surfaces. These coatings typically consist of lubricants such as waxes, polyethylene, polyvinyl alcohol, and silicone. Since cold-end coatings make the glass surface more slippery, it is important to check the compatibility of the cold-end treatment with adhesives used in labeling.

11.5 Other packaging types

11.5.1 Aseptic packaging

Aseptic packaging is the filling of a commercially sterilized product into a sterilized container under aseptic conditions and then sealing it hermetically to prevent contamination. Therefore, the sterility can be maintained throughout the handling and distribution process. The aseptic packaging permits shorter heat exposure for the food than typical thermal sterilization processes such as canning and retorting; therefore it generally results in superior food quality compared to typical thermal sterilization. Because of the separate package and food product sterilization, the selection of material and container design can be more flexible than in traditional thermal sterilization.

The required microbial count reduction (referred as log reduction) for the sterilization of a food contact packaging material is determined by the type of product. For non-sterile acidic products (pH <4.5), a minimum 4-log reduction in bacterial spores is required. For sterile, neutral, low-acid products (pH >4.5), a 6-log reduction is required. In addition, if sterility against *Clostridium botulinum* endospores is required, a 12-log reduction is required, and the process is called commercial sterilization. The sterilization methods for aseptic packaging materials include irradiation (such as ultraviolet rays, infrared rays, and ionizing radiation), heat (such as saturated steam, superheated steam, hot air, hot air and steam), and chemical treatment (such as hydrogen peroxide, ethylene oxide, peracetic acid). These processes can be used either individually or in combination.

The type of aseptic packaging material used is influenced by the nature of the product, the cost of both product and packaging, and the preference of consumers. The most widely used aseptic package is the paperboard laminated carton. The typical structure of this material consists of unbleached or bleached paperboard, polyethylene, and aluminum foil. The laminated structure is impermeable to liquid, gas, and light. The detailed structure of a typical paperboard carton (which is produced by Tetra Pak) is shown in Figure 11.5.

Aseptic packages can also be in the form of cans, bottles, pouches, trays, or cups. Can type aseptic packages are the same basic types of metal cans as in the regular canning process: tinplate, ECCS, and aluminum. Under an aseptic packaging process, the heating time for sterilization and food quality are the same for both large and small containers, while the traditional canning process has longer heating times for larger containers. Bottle type aseptic packages are produced from plastics as an economical alternative to glass for non-returnable containers. HDPE, PP, and PET are the most commonly used materials for this type of package. Pouch type aseptic packages are made from similar laminated paperboard structures. Also, multilayer films containing LLDPE and

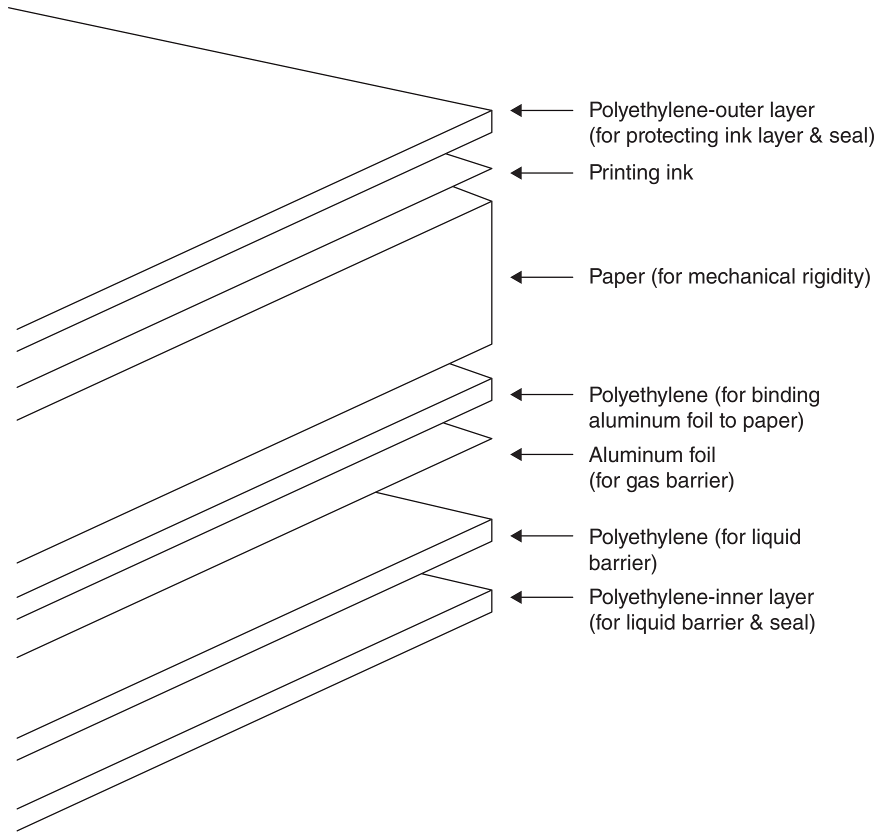

Figure 11.5 The structure of a typical laminated paperboard carton for aseptic packaging.

EVOH are used. Cup type aseptic packages are produced from HIPS, PP, or multilayer film. Multilayer films are the choice when high barrier properties are required. PVDC or EVOH is typically used as the barrier layer.

Maintaining the package integrity during distribution and handling is one of the most important issues in aseptic food packaging. Thus, various integrity tests are used commercially. Typically, electrolytic testing, dye penetration or vacuum leak tests are used for quality control during manufacturing. However, these traditional methods are destructive and therefore it is impossible to test and reject all faulty packages in the processing line. Thus, non-destructive test methods, such as gas leak detectors and ultrasound techniques, are gaining more attention from industry.

11.5.2 Modified atmosphere packaging

Modified atmosphere packaging (MAP) is based on modifying or altering the atmosphere inside the package to prolong shelf life and maintain quality of products. The modification of the atmosphere can be achieved actively or passively. In active type MAP, the optimum gaseous environment is obtained by flushing a controlled mixture of gases in a package ("gas flush"). The passive type of MAP modifies the optimum gaseous environment in a package by a combination of the food's respiration and the metabolism of microorganisms associated with the food and the permeability of the packaging. With the optimized gaseous atmosphere, degradation reactions in foods such as enzyme activity, oxidation, moisture loss, and postharvest metabolic activities as well as the growth of microorganisms are delayed. The three main gases used for MAP are nitrogen (N_2), carbon dioxide (CO_2), and oxygen (O_2). They are used either alone or, in most cases, in combination. Mixtures of carbon dioxide (CO) and argon (Ar) are also utilized commercially. Examples of gas mixtures that are used for fresh and processed foods are shown in Table 11.1.

Table 11.1 Examples of optimum headspace gas mixtures (%) and storage temperature for fresh and processed food products

Product	Temperature (°C)	Oxygen (%)	Carbon dioxide (%)	Nitrogen (%)
Snack	23	0	20–30	70–80
Bread	23	0	60–70	30–40
Cake	23	0	60	40
Cheese (hard)	4	0	60	40
Cheese (soft)	4	0	30	70
Pasta	4	0	80	20
Pizza	5	0–10	40–60	40–60
White fish	0–2	30	40	30
Oily fish	0–2	0	60	40
Shrimp	0–2	30	40	30
Fresh red meat	0–2	40–80	20	0
Cooked/cured meat	1–3	0	30	70
Pork	0–2	40–80	20	0
Poultry	0–2	0	20–100	
Sausage	4	0	80	20
Apples	0–3	1–3	0–3	
Banana	12–15	2–5	2–5	
Broccoli	0–5	5–10	1–2	
Lettuce	0–5	2–3	5–6	
Tomato	7–12	4	4	

Adapted from: FDA (2001), Brody (2000), Parry (1993).

11.5.2.0.1 Nitrogen (N_2)

Nitrogen is the most commonly used gas in MAP. It is an inert gas with no odor or taste. Nitrogen also has low solubility in water (0.009 g/kg at 20 °C). Nitrogen does not directly provide any microbial retardation but it delays aerobic microbial growth and oxidation by replacing oxygen.

11.5.2.0.2 Carbon dioxide (CO_2)

Carbon dioxide is colorless with a slightly pungent odor. The most important function of this gas is related to its bacteriostatic and fungistatic properties. Usually, a higher concentration is more effective against microorganisms. However, color changes and acid tastes have been reported by several researchers due to exposure to high CO_2. Carbon dioxide has high solubility in water (1.69 g/kg at 20 °C). Thus, packages containing moist foods with CO_2 in their headspace may collapse.

11.5.2.0.3 Oxygen (O_2)

Oxygen is a colorless, odorless, and highly reactive gas. It promotes food deteriorative reactions such as fat oxidation, browning reactions, and aerobic microbial growth. For this reason, the desired oxygen content in the headspace of most foods is often extremely low. However, oxygen is still needed for the retention of color in red meat and for fruit/vegetable respiration.

11.5.2.0.4 Carbon monoxide (CO)

Carbon monoxide is a colorless, tasteless, and odorless gas. When carbon monoxide combines with myoglobin, a bright red pigment (carboxymyoglobin) is formed, which is more stable than normal red meat pigment (oxymyoglobin). The use of carbon monoxide is not for quality issues but for its visual effect. Since carbon monoxide is a toxic and highly flammable gas, its commercial use is limited. In the US, carbon monoxide is currently used for red meat but the level of its use is limited to 0.4% (FDA, 2005a).

11.5.2.0.5 Argon (Ar)

Argon is a chemically inert, colorless, tasteless, and odorless gas which is denser and heavier than air. Compared to nitrogen, argon is a more effective gas for use in flushing out air. However, due to the high cost of argon, nitrogen is mostly used for flushing.

11.5.2.1 Modified atmosphere packaging for meat

For red meat, oxygen is necessary to maintain the red color of oxymyoglobin in unprocessed meats. On the other hand, a low oxygen level is desired to prevent the growth of microorganisms and oxidative rancidity of fat. Typically, the shelf life of fresh red meat is extended by packaging it in an atmosphere of 20% CO_2, 60–80% O_2, and up to 20% N_2. However, off-odors and rancidity have been reported in meats stored at high O_2 concentrations (Taylor, 1985). Thus, maintaining a low temperature (0–2 °C) is desired when high-O_2 MAP is used.

Poultry has low myoglobin content so it does not need oxygen to maintain its color. A higher CO_2 concentration (20–100%) is possible to extend the shelf life. However, a few studies report color change with high CO_2 concentration in poultry products (Dawson, 2004).

11.5.2.2 Modified atmosphere packaging for seafood

Seafood such as fish and shellfish is highly perishable owing to its high water activity (a_w), pH, and the presence of autolytic enzymes, which cause rapid development of undesirable odors. A low oxygen atmosphere can delay the occurrence of undesirable odor and growth of aerobic microorganisms. For example, packaging tilapia fillets in 75% CO_2:25% N_2 extended their shelf life up to 80 days at 4 °C (Sivertsvik et al., 2002). However, fresh fish may be contaminated with the anaerobic C. *botulinum* either as a result of being present in the microbiota of the fish ecosystem or due to postcatch contamination during processing. A low oxygen atmosphere poses a potential threat for a packaged fish to become toxic prior to spoilage. To assure the safety of MAP fish products, the product must be maintained at or below 3 °C at all times. Since chilled storage control is a critical factor to determine the shelf life, some companies use time temperature indicators (TTI) to monitor for temperature abuse.

11.5.2.3 Modified atmosphere packaging for fresh fruits and vegetables

Fresh fruits and vegetables keep consuming O_2 and emitting CO_2 even after harvest. The purpose of MAP for fresh fruits and vegetables is to minimize the respiration and senescence without causing suffocation and damage to metabolic activity that rapidly reduces their shelf life. However, a low oxygen and high CO_2 atmosphere that develops inside the package due to respiration of the product may result in the accumulation of ethanol and acetaldehyde, and fermentation could start. Thus, the package material needs to be somewhat permeable to oxygen and CO_2 to allow the transfer of the gases from outside and inside. The change in gas composition during storage depends on the permeability of the container to water vapor and gas, storage temperature, and the mass of the food.

11.5.3 Active packaging in food processing

Active packaging is an important and rapidly growing area. There are several different definitions that can be found in the literature for active packaging.This type of packaging usually involves an interaction between the packaging components and the food product beyond the inert passive barrier function of the packaging material (Labuza & Breene, 1989; Soroka, 2008b). The major active packaging technologies include oxygen scavengers, moisture absorbers, antimicrobial agent releasers, ethylene scavengers, flavor/odor absorbers, and temperature control packaging. In order to apply this technology, the major deteriorative factor(s) for food products should be understood. For example, the shelf life of a packaged food is affected by numerous factors such as acidity (pH), water activity (a_w), respiration rate, oxidation, microbial spoilage, temperature, etc. By carefully considering all of these factors, active packaging can be developed and applied to maintain the quality of the product and/or to extend its shelf life. Active agents are contained in sachets or incorporated directly into packaging containers.

11.5.3.1 Oxygen scavengers

Oxygen scavengers are the most commercially applied technology in the active packaging market. By scavenging oxygen molecules in the package headspace, oxidative damage to food components such as oil, flavors, vitamins, color, etc. can be prevented. In addition, reduced O_2 concentration in the package retards the growth of aerobic bacteria and mold.

The basic principle of oxygen scavenging is related to oxidation of the scavenging agents (either metallic or non-metallic based materials) to consume oxygen. The most common O_2 scavengers used in the food industry are sachets with iron powder, which are highly permeable to oxygen. By using iron powder, the O_2 concentration in the headspace can be reduced to less than 0.01% while vacuum or gas flushing typically achieves 0.3–3.0% residual O_2 levels (Robertson, 2007). The metal-based oxygen scavengers normally cannot pass the metal detectors on the packaging lines and cannot provide transparent packages if they are directly incorporated into packages. Non-metallic O_2 scavengers, such as ascorbic acid or glucose oxidase, can be used as an alternative choice. However, the use of non-metallic O_2 scavengers is not widespread.

O_2 scavengers can be incorporated into plastic film/sheet when there are market concerns about accidental consumption of sachets or when an O_2 scavenger needs to be used for liquid foods. In this case, the O_2 scavenger-impregnated layer is typically sandwiched between film layers. The outside layer provides high oxygen protection and the inner layer prevents direct contact between the scavenger-containing matrix layer and the food.

11.5.3.2 Moisture absorbers

Moisture in packages is a major cause of food deterioration such as microbial growth-related spoilage and product softening. Moisture-absorbing sachets are used in food packaging for humidity control. Several desiccants such as silica gel, calcium oxide, and activated clays and minerals are typically contained in sachets. Drip-absorbent pads and sheets are also used to absorb liquid in high a_w foods such as meats, fish, poultry, fruits, and vegetables. A superabsorbent polymer is sandwiched by a microporous non-woven plastic film such as polyethylene or polypropylene. Polyacrylate salts, carboxymethyl cellulose (CMC), and starch co-polymers are typically used as the absorbent polymer.

11.5.3.3 Antimicrobial agent releasers

Typically, surface contamination during food handling and transportation is one of the most common sources of food-borne illness, and lower amounts of antimicrobial agents are required to control the surface microbial contamination/growth if they are incorporated into or onto packaging material rather than directly added into the food itself. There are two mechanisms for antimicrobial action: one is controlling microbial growth by slow and controlled release (or migration) of the antimicrobial agents over the product shelf life. The other type is controlling microbial growth by contact without release of the antimicrobial agents, which are immobilized on the surface of the package. Despite the large number of experimental studies on antimicrobial packaging, the technology has not been widely used in food markets yet, because of cost or regulatory constraints. An example of a commercial application of an antimicrobial packaging is silver ion-based film. This film is an effective antimicrobial agent with very low human toxicity and it has been used in food containers. Other examples of antimicrobials used (or studied) include nisin, pediocin, organic acids, grapefruit seed extract, cinnamon, and horseradish (Han, 2003).

11.5.3.4 Ethylene scavengers

Ethylene works as a plant growth regulator which accelerates the respiration rate and senescence of fruits and vegetables. Removing ethylene from the environment can extend the shelf life of horticultural products. One of the most common ethylene scavengers is made from potassium permanganate ($KMnO_4$) immobilized on an inert mineral substrate such as alumina or silica gel. Activated carbon-based scavengers with various metal catalysts are also used as effective ethylene scavengers. In recent years, packaging films and bags have been commercialized based on the reputed ability of certain finely dispersed minerals to absorb ethylene (such as clays, zeolites, coral, ceramics, etc.) (Rooney, 2005).

11.5.3.5 Flavor and odor absorbers

Undesirable flavor scalping by the packaging material can result in the loss of desirable food flavors, while foods can pick up undesirable odors or flavors from the package or the surrounding environment. For example, fruit juices in PET bottles or water in HDPE bottles can absorb unwanted odors that result from aldehydes such as hexanal and heptanal originating in oxidation of the plastics. Another example is that an unpleasant "confinement odor" can accumulate inside PE bags in a distribution center. One type of flavor/odor-absorbing technology is based on a molecular sieve with pore sizes of approximately 5 nm. Cyclodextrin is a common example of an odor absorber. Wood (2011) reported that cyclodextrin, grafted to a PE layer, was applied to military ration pouches to absorb accumulated odor from food decomposition. Synthetic aluminosilicate zeolite, which has a highly porous structure, has been incorporated in packaging materials, especially papers, to absorb odorous gases such as aldehyde (Day, 2003).

On the other hand, absorbers can also be used in a flavor/aroma-releasing system. Aroma compounds can be released inside the package to enhance the flavor/aroma of the product or outside the package to attract consumers to the products on a retail store shelf (Lagaron & Lopez-Rubio, 2009).

11.5.3.6 Temperature-controlled packages

Temperature-controlled active packages generally include self-heating and self-cooling systems. The fundamental concepts for self-heating are not new. An exothermic chemical reaction between CaO (quicklime) and a water-based solution generates heat. The challenging part of this system is optimizing the reaction and the thermal design of the container to provide an efficient, safe, and cost-effective package. Self-heating packages are commercially available for coffee, tea, and ready-to-eat meals. Self-cooling cans use endothermic chemical reactions; the latent heat of evaporating water is often used to produce the cooling effect. One example is dissolution of ammonium nitrate and chloride in water to cool the product (Day, 2008).

11.6 Sustainable food packaging

11.6.1 Recycling of food packaging

Food packaging has the largest demand for packaging industries, whether it is paper, plastics, glass, or metal. Finding or improving ways to reduce landfilled waste is important to meet current demands for environmentally friendly packaging (Arvanitoyannis & Kasaverti, 2008). Recycling can be defined as diverting materials from the solid waste stream for use as raw materials in the manufacture of new products. The overall recycling rate of packaging material in the US is 40%, and is far behind the rate in Europe, which is about 59% (Fischer & Davisen, 2010).

11.6.1.1 Recycling of paper and paperboard

Packaging materials are the largest sector in which recycled paper is used in the US, as shown in Figure 11.6. The recycling rate for paper and paperboard has been increasing during the last decade. In 2010, 37.7 million tonnes of paper and paperboard packaging waste were generated and 71.3% of the used material was recycled (EPA, 2010). Even if most types of paper are recyclable, recycled paper is not suitable for most food contact packaging applications because the recycling processes may allow contaminants to be present in the recycled paper products. In many applications, recycled paper is not used in direct contact with food, so migration is of little or no concern. Another issue is related to paper properties: recycled paper normally has a damaged and weak fiber structure. In order to obtain suitable physical and mechanical characteristics, mixing virgin and recovered fibers in different proportions is often required.

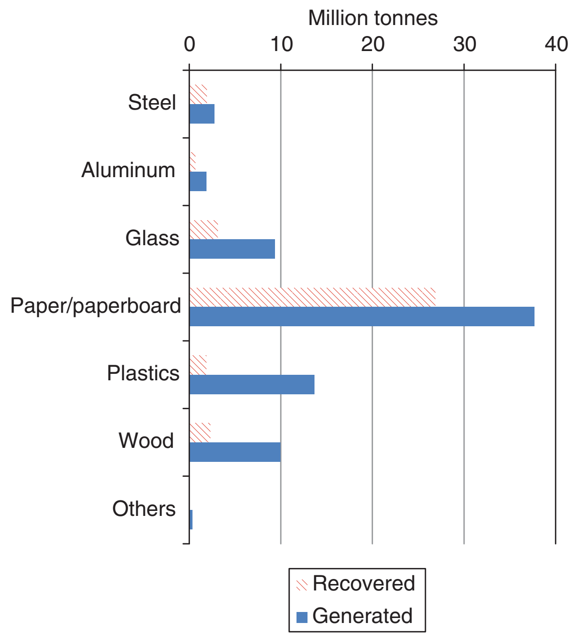

Figure 11.6 Generation and recovery of packaging materials in the United States (EPA 2010).

11.6.1.2 Recycling of glass

Glass is the next most recycled packaging material, in terms of weight recovered; 9.36 million tonnes of glass packaging waste were generated in the US in 2010, and 33.4% of the used material was recycled (EPA, 2010). Unlike paper-based material, the properties of glass are not affected by recycling. Cullet can be reprocessed into glass containers with physical properties identical to the original material. Glass recycling also reduces energy consumption: addition of 10% cullet reduces energy consumption by 2.5% (Dainelli, 2008). One of the major problems for food packaging applications originating from recycling is the presence of contaminants. Contaminants such as metals, papers, plastics, organic substances, ceramics, and heat-resistant glass (such as borosilicates), if not removed, can cause problems in making new food containers. Combination with colored glass is another problem, especially in the manufacture of colorless glass. This can result in off-color containers that are not acceptable for demanding applications such as food packaging. Mixed color cullet may be used for alternative applications such as abrasive paper, water filtration media, construction materials, and so on. Efficiently removing or sorting these contaminants or colored cullet requires a high level of investment. In addition, cullet is heavy and therefore expensive to ship. Collection within an acceptable transport distance is a critical point in glass recycling.

11.6.1.3 Recycling of aluminum

Aluminum is a metal largely used for industrial and consumer goods applications; 1.9 million tonnes of total aluminum packaging waste were generated in the US in 2010, and 35.8% of the used material was recycled (EPA, 2010). Like glass, recycled aluminum does not lose its physical properties and is safe for food packaging. Using recycled aluminum can save 75–90% of energy compared with its production from natural sources (Dainelli, 2008). Collection of aluminum for recycling is through a combination of deposit, curbside, and drop-off programs. During the recycling process, aluminum is easily separated from other metals. Since it is lighter and not magnetic, iron or other ferrous metals can be separated using a magnetic separator or flotation. Internal coatings, printed ink, and any other organic contaminants are destroyed during the recycling process.

11.6.1.4 Recycling of plastics

Plastics are recycled the least of the major packaging materials in the US; 13.68 million tonnes of plastic packaging waste was generated in the US in 2010, and 13.5% of the used material was recycled (EPA, 2010). During recycling, plastics can undergo several types of reactions such as chain scission, cross-linking, oxidation, and hydrolysis. Thus, the overall physical performance of the recycled plastics may decrease significantly. In addition, all recycled plastics cannot be mixed together due to their chemical incompatibility. In most applications, achieving good performance properties requires separation of the recycled plastics by resin type. Therefore, recycling of plastic packaging wastes is more difficult and costly than that of some other packaging materials. Energy recovery, such as incineration, may be the preferred option for multilayer plastics which cannot be separated by type, while cleaning and reprocessing into pellets for use in new plastic products is often the best choice for homogeneous plastics. Another option in some cases is depolymerization to monomers, purification, and repolymerization.

Since the potential migration of contaminants to food or other products is often a concern, most recycled plastics are used for non-food applications, including packaging containers, film and sheet, and also non-packaging applications such as fiber and carpet. In order to obtain food contact-grade plastic, the recycled plastics need to be processed and used in a way that effectively removes the potential for such contamination.

One option, as mentioned above, is chemical recycling, in which after depolymerization, the monomers are purified and repolymerized. Polymers produced in this way are identical to those produced from ordinary raw materials. Chemical recycling can be used for PET and PA, but is often not economical.

Another option for recycled plastic in food packaging is using it as a component in a multilayer structure. The recycled plastic is sandwiched inside, and a “barrier” layer of virgin plastic separates the recycled plastic from the product.

Another widely used option for PET is intensive cleaning to remove most potential contaminants. A number of companies have received “non-objection” letters from the US FDA for plastics recycling processes that have been demonstrated to remove potential contaminants from recycled PET streams to a degree that makes them acceptable for food contact (FDA, 2008). One example is the Superclean process, which consists of a series of processes that can remove the volatile contaminants as well as increase the viscosity of the recycled PET so that it is suitable for injection blow molding (Franz & Welle, 2002).

Most “non-objection” letters for recycled plastics have been issued for PET recycling processes. HDPE is both more susceptible to sorption of contaminants and more difficult to clean. While there have been a few processes approved for use of recycled HDPE in food packaging, there is little commercial use. On the other hand, recycled PET is used to a considerable extent in food packaging applications.

11.6.2 Biodegradable and compostable food packaging

Due to growing concerns about waste disposal problems and the environmental effects of petroleum-based plastics, natural biopolymers derived from renewable sources that are biodegradable appear to be a good alternative to conventional plastics. In addition, in recent times, oil prices have increased markedly. These facts have caused increased interest in non-petroleum based biodegradable polymers. The biodegradation takes place through the action of enzymes and/or biochemical deterioration associated with living organisms, and the biodegradability depends not on the raw material sources to produce the polymer but rather on the chemical structure of the polymer and the environmental conditions because chemical structure, such as the chemical linkage, pending groups, etc., is related to susceptibility to degradation, and environmental condition is related to living organisms' activities.

The common challenges in using biodegradable packaging materials are ensuring durability to maintain their mechanical and/or barrier properties during the product's shelf life, and then, ideally, the ability to biodegrade quickly on disposal. Ideally, the materials need to function in a similar way to conventional packaging in filling and sealing equipment with equivalent costs. Biobased biodegradable polymers can be classified into three main categories according to their origin and method of production (van Tuil et al., 2000).

• Polymers directly extracted/removed from biomaterials (for example, starch, cellulose, casein, etc.).
• Polymers produced by classic chemical synthesis from monomers produced from biomaterials (for example, polylactide polymerized from lactic acid monomers).
• Polymers produced directly by microorganisms (for example, polyhydroxyalkanoates).

A schematic presentation of these three categories is given in Figure 11.7.

11.6.2.1 Biodegradable polymers from agricultural crops

Polymers produced from starch are examples for this class. Starch is a widely available, environmentally friendly material with low cost. Corn is currently the most commonly used source of starch for bioplastics. However, potato, wheat, rice, barley, and oats can also be used as

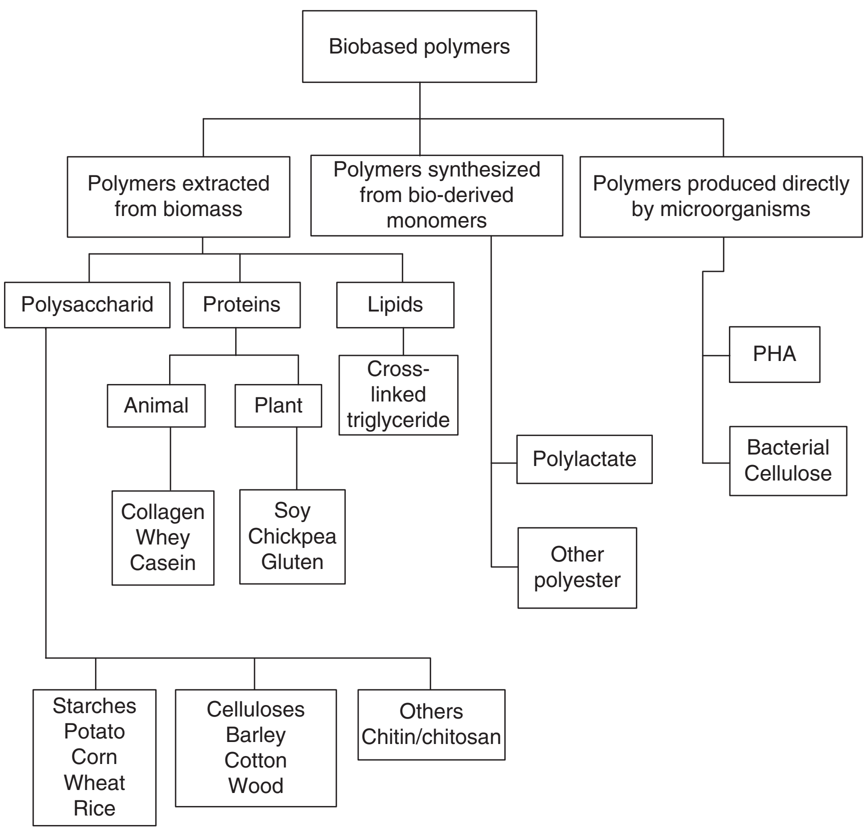

Figure 11.7 Biobased polymers for food packaging (from van Tuil et al., 2000).

starch sources (Liu, 2006). Without modification, starch films are hydrophilic and have relatively poor mechanical strength. They cannot be used for packaging applications. The brittleness of starch-based bioplastics can be decreased by using biodegradable plasticizers, including glycerol and other low molecular weight polyhydroxy compounds, polyethers, etc. (van Tuil et al., 2000).

Cellulose is the most widespread polysaccharide resource produced by plants. Cellulose is composed of glucose monomers that form a linear polymer with very long macromolecular chains. Cellulose is highly crystalline, brittle, infusible, and insoluble in all organic solvents (Chandra et al., 2007). These properties make cellulose impossible to process without modification. Cellophane films are produced by chemical modification of cellulose to render it soluble, and then regeneration of the cellulose after it is formed into film.

Another common practice is to use cellulose derivatives (cellulosic plastics) to improve the properties. The derivatives, such as ethers, esters and acetals, are produced by the reaction of one or more hydroxyl groups in the repeating unit, and can impart good film-forming properties. Cellulosic plastics are used for wrapping films, and for injection molded or blow molded containers. Tenite® (Eastman, USA), Bioceta® (Mazzucchelli, Italy), Fasal® (IFA, Austria), and Natureflex® (UCB, Germany) are trade names of some cellulose-based polymers.

11.6.2.2 Biodegradable polymers synthesized from bio-derived monomers

Polylactic acid (PLA) is a biodegradable, thermoplastic polyester that is derived from lactic acid. Lactic acid can be produced economically by microbial fermentation of glucose obtained from biomaterials such as corn or wheat starch, lactose in whey, or sucrose. PLA is now produced on a comparatively large scale. PLA is usually obtained from ring-opening condensation of lactide, which is a lactic acid dimer. Two forms of the monomeric acid (D- or L-lactic acid) exist. The properties of PLAs can be varied by adjusting the relative amounts of the two lactic acid isomers (D- or L-) in the polymer. For example, 100% L-lactic acid or 100% D-lactic acid forms highly crystalline PLA whereas amorphous PLA is obtained from DL-co-polymers across a wide composition range. The L-isomer is predominant in most PLA resins as most lactic acid obtained from biological sources is the L form; 90%L/10%D PLA is a common formulation. The formation is able to crystallize but melts more easily than 100%L and is suitable for production of packaging films. Different companies have commercialized PLA with various ratios of D/L lactide, with trade names including Natureworks ®, Galacid®, Heplon®, etc.

Polylactic acids generally have reasonable moisture and oxygen barrier properties and are suitable for various plastic package forming processes such as blown and cast film, injection molding, and vacuum forming. PLA is currently utilized in wraps for bakery and confectionery products, paperboard coatings for cartons, disposable foodservice tableware items, containers for fresh produce, and water bottles. The rate of degradation of PLA depends on the degree of crystallinity. Increasing the amount of D-isomer in predominantly L-PLA tends to suppress crystallinity and therefore increase the rate of biodegradation. There has been some research on enhancing the biodegradability of PLA by grafting with chitosan (Luckachan & Pillai, 2006).

11.6.2.3 Biodegradable polymers produced directly by microorganisms

Poly(β-hydroxyalcanoate)s (PHAs) are natural polyesters which are produced by bacteria from sugars or lipids. They are actually “grown” inside the cellular structure and then harvested. The use of PHAs is currently limited due to their high production costs. The performance properties are similar to conventional plastics, but the polymers are completely biodegradable. Thus, PHAs have potential as biodegradable alternative materials for conventional bulk commodity plastics (Foster et al., 2001). One of the family of PHAs, polyhydroxybutyrate (PHB), is the most commonly produced and researched bioplastic. PHB has high thermal resistance and water barrier properties. However, a narrow processability window and low impact resistance have hampered widespread use of PHB for packaging application. Blends of PHB with other polymers may improve its properties. For example, poly(ethylene oxide), poly(vinyl butyral), poly(vinyl acetate), poly(vinylphenol), cellulose acetate butyrate, chitin, and chitosan have been studied as blend materials with PHB. Another common method to improve the processability of PHB is to induce the microorganisms to form a co-polymer rather than the homopolymer. Polyhydroxybutyrate-valerate, PHBV, is the most common of these.

11.6.2.4 Synthetic biodegradable polymers

In addition to the biodegradable plastics based on natural substrates, there are synthetic biodegradable plastics produced from petrochemical feedstocks that have groups which are susceptible to hydrolytic microbial attack. Polycaprolactone (PCL) is a semi-crystalline aliphatic polyester which has a relatively low melting point (60 °C). It is completely biodegradable in marine, sewage, sludge, soil, and compost ecosystems (Khatiwala et al. 2008).

Polyvinyl alcohol (PVOH) is another synthetic biodegradable polymer which is completely soluble in water. The combination of starch and PVOH as a biodegradable packaging material has been studied since 1970. Currently, it is used to produce starch-based loose fillers as a substitute for expanded PS. Other types of synthetic biodegradable polymers include polyesters, polyamides, polyurethanes and polyureas, poly(amide-enamine)s, polyanhydrides (Chandra et al., 1998; Nair & Laurencin, 2007).

Synthetic polymers can be manipulated for a wide range of properties to obtain required mechanical properties (flexibility, toughness, etc.) as well as the degree of degradation. Rather than food packaging, the application of synthetic biodegradable polymers has been gaining more attention in the biomedical area such as tissue engineering scaffolds, orthopedic fixation devices, etc. (Gunatillake at al., 2006).

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Paper No.: 12
Paper Title: FOOD PACKAGING TECHNOLOGY
Module – 6: Glass as Packaging Material

6.1 Introduction

Glass is defined as ‘an inorganic product of fusion which has cooled to a rigid state without crystallizing’. Glass is made by cooling a heated, fused mixture of silicates, lime and soda to the point of fusion. After cooling, it attains a condition which is continuous with, and similar to, the liquid state of that substance, but which, as a result of a reversible change in viscosity, has attained so high a degree of viscosity as to be for all practical purposes solid.

6.1.1 Glass packaging

The two main types of glass container used in food packaging are

1. Bottles, which have narrow necks,
2. Jars and pots, which have wide openings.

6.1.2 Glass containers market sectors for foods and drinks

A wide range of foods is packed in glass containers. Examples are as follows: instant coffee, dry mixes, spices, processed baby foods, dairy products, sugar preserves (jams and marmalades), spreads, syrups, processed fruit, vegetables, fish and meat products, mustards and condiments etc. Glass bottles are widely used for beers, wines, spirits, liqueurs, soft drinks and mineral waters. Within these categories of food and drinks, the products range from dry powders and granules to liquids, some of which are carbonated and packed under pressure, and products which are heat sterilized.

6.2 Glass composition

6.2.1 White flint (clear glass)

Colourless glass, known as white flint, is derived from soda, lime and silica. This composition also forms the basis for all other glass colours. A typical composition would be: silica (SiO_2) 72%, from high purity sand; lime (CaO) 12%, from limestone (calcium carbonate); soda (Na_2O) 12%, from soda ash; alumina (Al_2O_3), present in some of the other raw materials or in feldspar-type aluminous material; magnesia (MgO) and potash (K_2O), ingredients not normally added but present in the other materials.

6.2.2 Pale green (half white)

Where slightly less pure materials are used, the iron content (Fe_2O_3) rises and a pale green glass is produced. Chromium oxide (Cr_2O_3) can be added to produce a slightly denser blue green colour.

6.2.3 Dark green

This colour is also obtained by the addition of chromium oxide and iron oxide.

6.2.4 Amber (brown in various colour densities)

Amber is usually obtained by melting a composition containing iron oxide under strongly reduced conditions. Carbon is also added. Amber glass has UV protection properties and could well be suited for use with light-sensitive products.

6.2.5 Blue

Blue glass is usually obtained by the addition of cobalt to a low-iron glass. Almost any coloured glass can be produced either by furnace operation or by glass colouring in the conditioning forehearth. The latter operation is an expensive way of producing glass and commands a premium product price. Forehearth colours would generally be outside the target price of most carbonated soft drinks.

6.3 Attributes of food packaged in glass containers

The glass package has a modern profile with distinct advantages, including:

6.3.1 Quality image

Consumer research by brand owners has consistently indicated that consumers attach a high quality perception to glass packaged products and they are prepared to pay a premium for them, for specific products such as spirits and liqueurs.

6.3.2 Transparency

It is a distinct advantage for the purchaser to be able to see the product in many cases, e.g. processed fruit and vegetables.

6.3.3 Surface texture

Whilst most glass is produced with a smooth surface, other possibilities also exist, for example, for an overall roughened ice-like effect or specific surface designs on the surface, such as text or coats of arms. These effects emanate from the moulding but subsequent acid etch treatment is another option.

6.3.4 Colour

A range of colours are possible based on choice of raw materials. Facilities exist for producing smaller quantities of nonmainstream colours, e.g. Stolzle’s feeder colour system.

6.3.5 Decorative possibilities

Including ceramic printing, powder coating, coloured and plain printed plastic sleeving and a range of labelling options.

6.3.6 Impermeability

For all practical purposes in connection with the packaging of food, glass is impermeable.

6.3.7 Chemical integrity

Glass is chemically resistant to all food products, both liquid and solid. It is odourless.

6.3.8 Design potential

Distinctive shapes are often used to enhance product and brand recognition.

6.3.9 Heat processable

Glass is thermally stable, which makes it suitable for the hot-filling and the in-container heat sterilization and pasteurization of food products.

6.3.10 Microwaveable

Glass is open to microwave penetration and food can be reheated in the container. Removal of the closures is recommended, as a safety measure, before heating commences, although the closure can be left loosely applied to prevent splashing in the microwave oven. Developments are in hand to ensure that the closure releases even when not initially slackened.

6.3.11 Tamper evident

Glass is resistant to penetration by syringes. Container closures can be readily tamper-evidenced by the application of shrinkable plastic sleeves or in-built tamper evident bands. Glass can quite readily accept preformed metal and roll-on metal closures, which also provide enhanced tamper evidence.

6.3.12 Ease of opening

The rigidity of the container offers improved ease of opening and reduces the risk of closure misalignment compared with plastic containers, although it is recognized that vacuum packed food products can be difficult to open. Technology in the development of lubricants in closure seals, improved application of glass surface treatments together with improved control of filling and retorting all combine to reduce the difficulty of closure removal. However, it is essential in order to maintain shelf life that sufficient closure torque is retained, to ensure vacuum retention with no closure back-off during processing and distribution.

6.3.13 UV protection

Amber glass offers UV protection to the product and, in some cases, green glass can offer partial UV protection.

6.3.14 Strength

Although glass is a brittle material glass containers have high top load strength making them easy to handle during filling and distribution. Whilst the weight factor of glass is unfavourable compared with plastics, considerable savings are to be made in warehousing and distribution costs. Glass containers can withstand high top loading with minimal secondary packaging. Glass is an elastic material and will absorb energy, up to a point, on impact. Impact resistance is improved by an even distribution of glass during container manufacture and subsequent treatment.

6.3.15 Hygiene

Glass surfaces are easily wetted and dried during washing and cleaning prior to filling.

6.3.16 Environmental benefits

Glass containers are returnable, reusable and recyclable. Significant savings in container weight have been achieved by technical advances in design, manufacture and handling.

6.4 Glass and glass container manufacture

6.4.1 Melting

Glass is melted in a furnace at temperatures of around 1350°C and is homogenized in the melting process, producing a bubble-free liquid. The molten glass is then allowed to flow through a temperature controlled channel (forehearth) to the forming machine, where it arrives via the feeder at the correct temperature to suit the container to be produced. For general containers, suitable for foods and carbonated beverages, this would be in the region of 1100°C.

6.4.2 Container forming

In the feeder, the molten glass is extruded through an orifice of known diameter at a predetermined rate and is cropped into a solid cylindrical shape. The cylinder of glass is known in the trade as a *gob* and is equivalent in weight to the container to be produced. The gob is allowed to free-fall through a series of deflectors into the forming machine, also known as the IS or individual section machine, where it enters the parison. The parison comprises a neck finish mould and a parison mould, mounted in an inverted position. The parison is formed by either pressing or blowing the gob to the shape of the parison mould. The parison is then reinverted, placed into the final mould and blown out to the shape of the final mould, from where it emerges at a temperature of approximately 650°C A container is said to have been produced by either the *press and blow* or *blow and blow* process.

In general terms, the press and blow process is used for jars and the blow and blow process for bottles. An alternative, for lightweight bottles, is the *narrow neck press and blow* process. The press and blow process is generally best suited to produce jars with a neck finish size of ≥35mm (≥1.25″); the other two processes are more suited to produce bottles with a neck finish size of ≤35mm (≤1.25″)

The narrow neck press and blow process offers better control of the glass distribution than the blow and blow process, allowing weight savings in the region of 30% to be made.

6.4.3 Design parameters

One of the design parameters to be borne in mind when looking at the functionality of a glass container is that the tilt angle for a wide-mouthed jar should be ≥22° and that for a bottle ≥16°. These parameters are indicative of the least degree of stability that the container can withstand.

6.4.4 Surface treatments

Once formed, surface treatment is applied to the container in two stages: hot end and cold end treatment, respectively.

6.4.5 Hot end treatment

The purpose of hot end surface treatment is to prevent surface damage whilst the bottle is still hot and to help maintain the strength of the container. The most common coating material deposited is tin oxide, although derivatives of titanium are also used. This treatment tends to generate high friction surfaces; to overcome this problem, a lubricant is added.

6.4.6 Cold end treatment

The second surface treatment is applied once the container has been annealed. Annealing is a process which reduces the residual strain in the container that has been introduced in the forming process. The purpose of the cold end treatment is to create a lubricated surface that does not break down under the influence of pressure or water, and aids the flow of containers through a high speed filling line. Application is by aqueous spray or vapour, care being taken to prevent entry of the spray into the container, the most commonly used lubricants being derivatives of polyester waxes or polyethylene. The surface tension resulting from this treatment can be measured by using Dynes indicating pens. Labelling compatibility should be discussed with either the adhesive supplier or the adhesive label supplier depending on the type of label to be used.

6.5 Thermal processing of glass packaged foods

Glass containers lend themselves to in-bottle sterilization and pasteurization for both hot and cold filled products. Subject to the headspace volume conditions being maintained and thermal shock ground rules being observed, no problems will be experienced.

In general terms, hot-fill products filled at 85°C and then cooled will require a minimum headspace of 5%, whilst a cold filled product requiring sterilization at 121°C will require a 6% minimum head space. In all cases the recommendations of the closure supplier should be obtained before preparing the design brief. It should be noted that the thermal shock of glass containers is twice as high when cooling down as when warming up. To avoid thermal shock, cool down differentials should not exceed 40°C and warm up differentials should not exceed 65°C.

Internal pressure resistance. A well-designed glass container can withstand an internal pressure of up to 10 bar (150 pounds per square inch), although the norm required rarely exceeds 5 bar. It is also capable of withstanding internal vacuum conditions and filling of thick concentrates, with steam-flushing of the headspace to produce the initial vacuum requirements for the closure seal.

6.6 Packing – due diligence in the use of glass containers

6.6.1 Receipt of deliveries

Glass containers are usually delivered on bulk palletized shrink-wrapped pallets. A check should be made for holes in the pallet shroud and broken glass on the pallet, and any damaged pallets rejected.

6.6.2 Storage/on-site warehousing

Pallets of glass must not be stored more than six high, they must be handled with care and not shunted. Fork-lift trucks should be guarded to prevent the lift masts contacting the glass. Where air rinser cleaning is used on the filling line, the empty glass containers should not be stored outside. Pallets damaged in on-site warehousing must not be forwarded to the filling area until they have been cleared of broken glass.

6.6.3 Depalletization

Plastic shrouds must be removed with care to prevent damage to the glass; if knives are used, the blade should be shrouded at all times, so as not to damage the glass. It is necessary to ensure that the layer pads between the glass containers are removed in such a way as to prevent any debris present from dropping onto the next layer of glass.

6.6.4 Cleaning operation

- *Air rinse*. The glass must be temperature-conditioned to prevent condensate forming on the inside, which would inhibit the removal of cardboard debris. The air pressure should be monitored to ensure that debris is not suspended and allowed to settle back into the container.
- *On-line water rinse*. Where hot-filling of the product takes place, it is essential to ensure that the temperature of the water is adequate to prevent thermal shock at the filler, i.e. not more than 60°C differential.
- *Returnable wash systems*. The washer feed area must be checked to ensure that the bottles enter the washer cups cleanly. A washer-full of bottles must not be left soaking overnight. In the longer term this would considerably weaken the container and could well create a reaction on the bottle surface between the hot end coating and the caustic in the washer. Where hot-filling is taking place, it is necessary to ensure that the correct temperature is reached to prevent thermal shock at the filler.

6.6.5 Filling operation

Clean-up instructions should be issued and displayed. It is essential to ensure that flood rinsing of the filler head in question is adequate to prevent contamination of further bottles. It is necessary to ensure that filling levels in the container comply with trading standards' requirements for measuring containers.

6.6.6 Capping

Clean-up instructions on the procedure to follow should breakage occur in the capper should be issued and displayed, and all breakages recorded. The application torque of the caps and vacuum levels must be checked at prescribed intervals, as must the cap security of carbonated products.

6.6.7 Pasteurization/sterilization

It is necessary to ensure that cooling water in the pasteurizer or sterilization retort does not exceed a differential of more than 40°C (104°F), to prevent thermal shock situations. The ideal temperature of the container after cooling is 40°C, which allows further drying of the closure and helps prevent rusting of metal closures. Air knives should be used to remove water from closures to further minimize the risk of rusting.

6.6.8 Labelling

Where self-adhesive labels are to be used, all traces of condensate must be eliminated to obtain the optimum conditions for label application. Adhesives must not be changed without informing the glass supplier, since this could affect the specification of adhesives/surface treatments.

6.6.9 Distribution

It is essential to ensure that the arrangement of the glass containers in the tray, usually plastic or corrugated fibreboard, is adequate to prevent undue movement during distribution, that the shrink-wrap is tight and that the batch coding is correct and visible.

6.6.10 Warehousing
The pallets of filled product must be carefully stacked to prevent isolated pockets of high loading that might create cut through in the lining compound of the container closures, as this would result in pack failures.

6.6.11 Quality management
The procedures of good management practice in the development, manufacture, filling, closing, processing (where appropriate), storage and distribution of food products in glass containers discussed in this chapter have been developed to ensure that product quality and hygiene standards are achieved along with consumer and product safety needs. Their application indicates *due diligence* in meeting these needs. It is essential that all procedures are clearly laid down, training is provided in their use and that regular checks are made on their implementation.

6.7 Environmental profile

6.7.1 Reuse
Glass containers can be reused for food use. The daily doorstep delivery of fresh milk in bottles and the collection of the empty bottles in the UK and collection of empty bottles of carbonated beverage are well established examples. There are wide disparities in the number of trips that can be expected depending on the location, with around 12 trips per bottle being the national average.

6.7.2 Recycling
Glass is one of the easiest materials to be recycled because it can be crushed, melted and reformed an infinite number of times with no deterioration of structure. It is the only packaging material that retains all its quality characteristics when it is recycled.

6.7.3 Reduction – lightweighting
In the period 1992–2002, it is claimed that the average weight of glass containers has been reduced by 40–50%.

6.8 Glass as a marketing tool
Glass packaging supports brand differentiation and product identification by the use of:

- Creative and unique shapes and surface textures
- Ceramic printing, acid etching and coating
- Labelling, both conventionally and by plastic shrink sleeving

Current developments include the use of metallic, thermochromic, photochromic finishes, UV activated fluorescent and translucent inks and the ability to incorporate embossed, foiled, velvet textured and holographic materials. These finishes are compatible with laser etching and offer the possibility of permanent traceability coding.

Paper No.: 12
Paper Title: FOOD PACKAGING TECHNOLOGY
Module – 01: Introduction to food packaging

1. INTRODUCTION

In today's world, packaging is universal and important too. It surrounds, enhances and protects the goods we buy, from processing and manufacturing through handling and storage to the final consumer. Without packaging, materials handling would be a difficult, inefficient and costly exercise and modern consumer marketing would be virtually impossible. Most of the containers in the market today are used to protect a specific quantity of product during procurement, storage, distribution and retail sales, although several are also designed for bulk supply. The quality of the individual package depends on the nature, uniqueness and value of the product besides the prevailing social practices and legislation.

The selection of a packaging, storage and distribution system will depend on existing economic ability, production and distribution efficiency, retailing pattern, consumer preferences and ecological aspects.

Despite the importance and key role which packaging plays, it is often regarded as a necessary evil or an unnecessary cost. Furthermore, in the view of many consumers packaging is, at best, somewhat unnecessary and at worst, a serious waste of resources and an environmental threat. Such an opinion arises because the functions which packaging has to do are either unknown or not considered fully. By the time most consumers come into contact with a package, its job in many cases is almost over, so it is understandable that the view that excessive packaging has been used has gained some belief.

The Packaging Institute International defines packaging as the enclosure of products, items or packages in a wrapped pouch, bag, box, cup, tray, can, tube, bottle or other container form to perform one or more of the following functions: containment; protection and/or preservation; communications; and utility or performance. If the device or container performs one or more of these functions it is considered a package.

2. FUNCTIONS OF PACKAGING

The functions of a package are "to preserve the quality and freshness of food, to add appeal to the food to attract consumers, and to facilitate its storage and distribution." The basic functions required of a package can be grouped under five major categories.

2.1 To Contain the Product

The primary function of any package is to contain the food and facilitate handling, storage, and distribution all the way from the manufacturer to the ultimate user or even the time the rest portion is utilized by the consumer. However, there are usually various levels of packaging. A primary package is one that comes into direct contact with the contained product, e.g., metal cans, glass jars, and plastic pouches. By law, a primary package must not yield any substance that may be injurious to the health of the consumer. Further development to facilitate handling is to bundle a series of primary packages together, and this lead to the concept of secondary packages. Examples of secondary package is corrugated box in which tins of apple juice are packed. As methods of handling and transportation have become more sophisticated, these secondary packages are often palletized and secured by strapping with metal or, more commonly, by shrink- or stretch-wrapped film to give yet another level of packaging, i.e tertiary packaging. In turn, these pallet loads may be packed into large metal containers, i.e., quaternary packaging for transportation over long distances by air, land, or sea. The secondary, tertiary and quaternary packaging is also known as packing. The following are basic functions during containing.

a. Adequate size and shape (trays to support biscuits in package)
b. Proper constructional features. No leakage, spillage, diffusion, i.e. loss prevention.
c. Package: Must contain the commodity in natural form (chips packed in Pillow pack, prevent damage)
d. No subsequent damage after packaging during handling transportation and storage.
e. Optimum compatibility (nontoxic, non soluble with product, No physical, chemical or biochemical changes/alteration, i.e. inert to the product.)
f. Containment or agglomeration - Small objects are typically grouped together in one package for reasons of efficiency. For example, a single box of 1000 pencils requires less physical handling than 1000 single pencils. Liquids, powders, and granules need containment.

2.2 To Protect the Product

One of the most important functions of any container is to protect the product contained against any form of loss, damage, deterioration, spoilage, or contamination that might be encountered throughout the distribution chain. Packaging can prevent physical damage, e.g., bruising caused by vibration shocks during transportation or stacking in a warehouse. Proper packaging will also prevent material loss, e.g., potatoes from a weak sack or juice from a leaky can. Packaging can also protect products against moisture loss or gain, dust, and light, which causes deterioration of some light-sensitive products. It can also protect the package contents against temperature fluctuations in the transit of chilled and frozen foods. Packaging can also be used to control the availability of oxygen to fruits and vegetables and to protect against loss of flavor or fragrance and help products retain their nutritional value. Proper packaging may also protect the product against microbial spoilage by bacteria, yeasts, and molds. It can also protect against microbiological spoilage of stored products due to rodents and insects.

Packaging protects the product against damages which may be due to different hazards viz. (a) Mechanical, (b) Environmental (c) Microbial & Biochemical and (d) Social

Table 1: Hazard, damage and protection of packaging materials

Sr. No	Storage	Hazard	Damage	Protection
I	Handling and transportation	Drop, shunting, shocks, vibrations, stack load, compression etc.	Breakage, loss of shape, dusting, seepage	Cushioning, blocking.
II	Storage	Stack load, compression, Attack by rodents and insects	Crushing, distortion sticking, spillage, contamination, spoilage	Adequate compression strength of package. resistance and repulsiveness to insects
III	Environment during storage transportation and distribution	Biological or otherwise	Contamination	Toughness of packaging material (to resist penetration).
		High/low humidity moisture/water.	Physical, chemical and biological deterioration due to loss/gain of moisture	Efficiency of closure providing. Water vapour barrier properties. Package desiccant etc.
		O_2	Oxidative rancidity	O_2 BARRIER VACUUM – O_2 N_2/CO_2 flushing

				packaging in impermeable package
		Light U.V. rays	Vitamin Destruction, Off flavour development, Oxidative rancidity, Bleaching of pigments	Use of opaque or dark coloured packaging material.
	Storage	Temperature	Change of state, Increase of moisture ingress Increased rate of deterioration	Heat insulation Use of poor conductor Use of reflective insulation
		Time	Gradual and slow changes occur and staling and other deteriorative changes occur	Early/immediate marketing (FIFO) Proper schedule of dispatching order providing Heat insulation Use of Barrier material

Barrier protection - A barrier from oxygen, water vapor, dust, etc., is often required. Permeation is a critical factor in design. Some packages contain desiccants or Oxygen absorbers to help extend shelf life. Modified atmospheres or controlled atmospheres are also maintained in some food packages. Keeping the contents clean, fresh, and safe for the intended shelf life is a primary function of the package.

2.3 Medium of information

An important function of any food package is to identify the product and its origin; to inform the consumer how to use the contents; to provide any other information needed or required; and very importantly, to attract the user and encourage purchase of the product. Package design has been an important and constantly evolving phenomenon for many years. Marketing communications and graphic design are applied to the surface of the package and in many cases the point of sale/display. The information a package can convey to the consumer may include the following:

1. Product manufacturing and best before dates
2. Proper storage conditions
3. Instructions for use
4. Size and number of servings or portions per pack
5. Nutritional information per serving
6. Manufacturer’s name and address
7. Cost
8. Suggested recipes
9. Country of origin
10. Information transmission - Packages and labels communicate how to use, transport recycle, or dispose of the package or product.

2.4 Means of minimizing costs:

An important factor often overlooked is that packaging actually reduces costs for the consumer. Packaging reduces food costs by reducing the cost of processing. Foods can be processed where they are grown, waste is treated at the processing plant, and shipping weights are reduced, thereby lowering the cost of transportation. The handling of packages in quantity is important for the economics of bulk storage, warehousing, transport, and distribution. Proper packaging facilitates efficient and mechanized handling, distribution, and marketing of products, thus reducing the high labour costs that would have to be absorbed into the price of the product. Thus, packaging not merely contains the product, but it is a process of bringing goods from the production point to the point of use in a most beneficial manner. This involves all aspects of handling, storage, preservation, distribution, advertising, sales promotion, preparation and various other facts of industry.

2.5 Means of selling product:

The packaging and labels can be used by marketers to encourage potential buyers to purchase the product. Packaging is often referred to as the “silent salesman.” Robertson (1992) concisely summarized the multifunction of packaging when he stated that “a package must protect what it sells and sell what it protects.” Packages can have features which add convenience in distribution, handling, display, sale, opening, reclosing, use, and reuse.

According to Jelen (1985), primary packages should have the following characteristics to facilitate the sale of products:

1. Aesthetic appeal
2. Non toxic
3. Transparent
4. Lightweight
5. Tamper evident
6. Easy to pick up and handle
7. Easy to fit into cupboards, shelves, refrigerators, etc.
8. Easy to open and dispense from
9. Easy to reclose
10. Returnable, recyclable, or reusable
11. Safe and presents no hazards in the way of broken glass or sharp jagged metal edges
12. Display the product
13. Glamorize: Create an illusion of something very precious, by decoration, embossing techniques and exotic closures, but it should not deceive the people.

The desirable polyfunctional properties of packaging materials are summarized in Table 2.

Table 2: Functional Requirements of Packaging Materials

No.	Functional Property	Specific Factors
1	Gas permeability	O_2, CO_2, N_2, H_2O vapor
2	Protection against environmental factors	Light, odor, microorganisms, moisture
3	Mechanical properties	Weight, elasticity, heat-sealability, mechanical sealability, strength (tensile, tear, impact, bursting)
4	Reactivity with food	Grease, acid, water, color
5	Marketing-related properties	Attractiveness, printability, cost
6	Convenience	Disposability, repeated use, resealability, secondary use
7	Aroma	Aroma compound barrier property

Source: Jelen, P. 1985. Food packaging technology. In *Introduction to Food Processing*, Reston Publishing, Reston, VA, pp. 249–266.

3. OTHER FUNCTIONS OF A PACKAGE:

1. **Dispensing:** Product not used all at once, remove a portion, without destroying/damaging the remaining product/container.
2. **Preserve:** Remaining product in container-Protection and preserve it for extended/desired period.
3. **Measuring / Portion control:** Single serving or single dosage package has a precise amount of contents to control usage. Bulk commodities (such as salt) can be divided into packages that are a more suitable size for individual households. It also aids the control of inventory: selling sealed one-liter-bottles of milk, rather than having people bring their own bottles to fill themselves.
4. **Security** - Packaging can play an important role in reducing the security risks of transport. Packages can be made with improved tamper resistance to deter tampering and also can have tamper-evident features to help indicate tampering. Packages can be engineered to help reduce the risks of package pilferage: Some package constructions are more resistant to pilferage and some have pilfer indicating seals. Packages may include authentication seals to help indicate that the package and contents are not counterfeit. Packages also can include anti-theft devices, such as dye-packs, RFID tags, or electronic article surveillance tags, that can be activated or detected by devices at exit points and require specialized tools to deactivate. Using packaging in this way is a means of loss prevention.

4. PACKAGING TYPES:

4.1 Terms used:

- **Package:** It cuts contact between material and outside influences. Package material comes in direct contact with the product (Packaging).
- **Pack:** Secondary container. **Packing material never comes in contact with product**.
- **Packing:** Number of containers/packages put together in big container is called packing.

Packaging may be looked at as several different types. For example a **transport package** or **distribution package** is the package form used to ship, store, and handle the product or inner packages. Some identify a **consumer package** as one which is directed toward a consumer or household. It is sometimes convenient to categorize packages by layer or function: "primary", secondary", etc.

1. **Primary packaging** is the material that first envelops the product and holds it. This usually is the smallest unit of distribution or use and is the package which is in direct contact with the contents (viz. butter in parchment paper).
2. **Secondary packaging** is outside the primary packaging – perhaps used to group primary packages together (viz. paper board pack containing butter wrapped in veg. parchment paper).
3. **Tertiary packaging** is used for bulk handling, warehouse storage and transport shipping. The most common form is a palletized unit load that packs tightly into containers (viz. Boxes containing 20-25 or 50 butter packs are put together).

These broad categories can be somewhat arbitrary. For example, depending on the use, a shrink wrap can be primary packaging when applied directly to the product, secondary packaging when combining smaller packages, and tertiary packaging on some distribution packs.

Table 3: Differences between packaging and packing

No.	Packaging	Packing
1	Comes in direct contact with the product	Never in direct contact
2	Called primary packaging material	Secondary / Tertiary / Quaternary
3	Should be food grade, non-toxic, tasteless, odourless, lowest possible migration	No strict requirements
4	Packaging- a must e.g. Ice cream party pack, Bulk pack, Ghee	May be done/may not be done. Packaging then packing e.g. CFB, cartons, etc. Bulk biscuit packs.
5	Materials used: Plastics / glass / metal / treated paper or their combination	CFB / Plastic board boxes, wood, metal, etc. Shrink/ stretch wrapping
6	Objectives: Mainly to contain, carry, protect. Help in selling, legal aspects, marketing / sale, technical, transportation	Mainly ease in transportation and protection of packages
7	Generally attractive. Not a must: Biscuits & rolls in a pack. E.g Kellogs flakes, toffee. The exposed portion must be attractive.	Generally not attractive. But if retail pack, secondary packing exposed to consumers then attractive: Butter carton
8	Recycled material never used.	Much preferred.

9	Selection of packaging material: Physico-chemical properties of product are considered.	Generally stress / strength properties puncture resistance / burst strength, folding endurance, environmental factors considered.
10	Keeping quality is determined by packaging material.	Generally not so.
11	Single unit packaging.	Generally multi unit packaging. Sometimes single unit also. Butter carton, Bag in box. Here packing materials should be more attractive / effective than packaging material.

Reasons for selecting a particular style/type of packaging are vast and varied, numerous and changing. Product and packaging are becoming so interdependent that one cannot separate/consider one without another. Greatest part of food is spent in some form of package.

5. REQUIREMENTS FOR PRODUCING SUCCESSFUL PACKAGE:

Some sets of facts are necessary to be known for producing a successful package (mainly related to product - package interaction and transportation):

5.1 Facts about the product:

a. The nature of the product, the material from which it is made and the manner in which it can deteriorate.
b. Its size and shape.
c. Its weight and density: eg. Powder – Bulk Density, size of tins
d. Its weakness-which parts will break, move about, become bent or scratch or abrase the box easily.
e. Its strengths: which part will withstand loads or pressures and which might be suitable for loading the product in the pack.
f. The effect of moisture and temperature changes on the product and whether it will absorb moisture or corrode.
g. Compatibility: whether the product is likely to be affected by any of the possible packaging materials, which items can be packed together, with protection if necessary and which items must not be packed together under any circumstances.

h. How far stripping down may be carried out to reduce the package size to a minimum such that the customer can handle them.

5.2 Facts about the transport hazards:

a. The type of transport-road, rail, sea or air.

b. The degree of control over the transport. Is it private or public transport?

c. The form of transport- bulk, freight container, unitized load, postal, passenger train, etc.

d. The mechanical conditions and duration of storage (manufacturer → State Distributor → District Distributor … Taluka / City → Retailer. The longer the journey or handling more strength is required in packaging & packing materials leading to higher cost).

e. The nature and intensity of mechanical and climatic hazards in transport, storage, retailing and use. Packaging / packing material has to withstand wide range of temperatures and relative humidity

f. Whether handling aids are available for loading and off-loading at all points between maker and user. (Viz. Lifts, Trolleys, Slip conveyers etc.)

g. The importance of minimum volume in relation to transport costs. Over packaging must be prevented.

5.2.1 Hazards may be:

a. Mechanical: Impact (vertical, horizontal), stationary package impacted by another, vibration, compression, Racking or deformation, piercing, puncturing, tearing etc.

b. Climatic hazard: (High / low temperature / pressure) light, liquid/water (fresh / polluted), dust, and water vapour, R.H.

c. Biological: (Microorganisms, fungi, moulds, bacteria, beetles, moths, flies, ants, termites, mites, rodents (rats and mice), birds.

5.2.2 Contamination by other goods:

- By materials of adjacent packs
- By leaking contents of adjacent packs
- Radioactivity.

6. CONCLUSION

Knowledge of the functions of packaging and the environments where it has to perform will lead to the optimization of package design and the development of real, cost-effective packaging.

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Paper No.: 12
Paper Title: FOOD PACKAGING TECHNOLOGY
Module – 07: Metal Packaging Materials

1 INTRODUCTION:

The commercial packaging of foods in metal containers began in the early 19th century, following on from the discovery in the 1790s by the French confectioner Nicolas Appert of a method of conserving all kinds of food substances in containers, a method to which the term canning is now applied indiscriminately, whether the container is made from tinplate, aluminum, glass or plastics. The earliest can makers were tin-smiths who turned out tin plate containers with skill and imagination, in a variety of sizes and shapes. Both ends were soldered to the body, with a hole about 25mm in diameter at the top. After can was filled through this hole a metal disc was soldered into place. Mechanization of the can making process was made possible by the development of a method called double seeming, to attach ends to the soldered can body. Even though many of the fundamental manufacturing processes, such as double seaming and body forming were developed in the late 19th century, the evolution of can making continues. Related technologies such as metallurgy and food engineering are also advancing, creating new applications for the metal packaging materials. Of the total estimated world market of metal cans about 78% is accounted for drink cans and about 18% for processed food cans. The remainder are aerosol and general line cans. Drink cans may be divided into those for non-carbonated drinks (liquid coffee, tea, sports drinks etc.) and carbonated beverages (soft drinks and beer), many of which pass through a pasteurisation process.

2 CONTAINER PERFORMANCE REQUIREMENTS

Metal packages for food products must perform the following basic functions if the contents are to be delivered to the ultimate consumer in a safe and wholesome manner:

1. Preserve and protect the product
2. Resist chemical actions of product
3. Withstand the handling and processing conditions
4. Withstand the external environment conditions

5. Have the correct dimensions and the ability to be practically interchangeable with similar products from other supply sources (when necessary)
6. Have the required shelf display properties at the point of sale
7. Provide easy opening and simple/safe product removal
8. Should be constructed from recyclable raw materials.

In addition, these functions must continue to be performed satisfactorily until well after the end of the stated shelf life period. Most filled food and drink containers for ambient shelf storage are subjected to some form of heat process to increase the shelf life of the product. The heat process cycles used to achieve this are particularly severe and the containers must be designed so as to withstand these conditions of temperature and pressure cycles in a steam or water atmosphere. After heat processing, when the can temperature has returned to ambient, there will normally be a negative pressure in the can, i.e. a vacuum. Under these conditions, the food product itself does not provide any strength to the can to resist external loads.

In the case of carbonated beverage cans, which form the bulk of drink cans filled, once the container is closed, the carbonation pressure continues to provide significant physical support to the container until the moment of opening. In the case of still liquids, such as juices, nitrogen gas may be used to provide the necessary internal pressure for rigidity and compression strength.

3. MERITS AND DEMERITS OF METAL PACKAGING MATERIALS

Metal cans are impermeable to moisture, gases and light. They are produced from readily available and highly recyclable materials. Metal cans are compatible with many products and offer high stacking strength, thermal stability and a good surface for decoration, printing and coating. They have potential for high-speed manufacturing and filling. Many designs today offer easy opening ends that do not require the tools to get the contents. Two-piece design of cans deletes the chances of leaking of its contents as there are no side and bottom seams.

But, the cost of setting up of a production line for cans is high. Food processors also need a variety of sizes for different products harvested in different seasons enhancing the cost further to achieve this diversity.

4. C O N T A I N E R   D E S I G N S

Regardless of the particular can-forming process used, the shapes of metal containers are very relevant to their cost, physical performance and compatibility with the filled product. For most metal food and drink containers the cost of the metal itself is 50–70% of the total container cost. The amount of metal in any particular container is the most significant cost item, and this is related to the metal thickness, temper and its surface area. In can design, metal thickness is determined by the need for physical performance in handling, processing and storage of the filled container. Surface area is determined by the volume contents and the shape of the container. For ease of manufacture and handling, most food and drink cans have a circular cross section. But, for different physical performance, cost and product uses, cans may vary from shallow to tall.

4.1 Can Configurations

The three basic types of cans are: three-piece cans, two-piece drawn and ironed cans and two-piece drawn and redrawn cans.

4.1.1 Three-piece Can

As the name suggests, it is made in three pieces: a body and two ends. The manufacture of three-piece cans involves the cutting of metal sheet into can-width strips on a machine called 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 body blanks are rolled, the corners are notched to remove the extra thickness of metal, and the side seam is curled into the ends and passed on to side seamers. Within three-piece category cans, there are three further classifications determined by the method used to join the side seam of the body cylinder. The methods are soldering, welding and cementing.

4.1.1.1 Soldered seams: For soldered cans, the edges of the blanks are bent, brushed with flux, passed over a gas flame and joined in a lap and lock seam while moving over a solder application seam, another burner smoothens the seam and wiper removes excess solder. The soldering seam is then treated with a lacquer. The body blank is flanged to receive the can bottom which is double seamed. The top of the can is usually applied after a filling operation. In the final step a spray coating is applied to the can interior, cured and tested for leaks.

4.1.1.2 Welded seams: The 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 edge inside the can is coated in a striping operation using powder coating which is cured by infra-red or high-frequency induction heating.

4.1.1.3 Cemented seams: The cemented side seams permit all-round lithography with no base strip required at the solder point. The body former curves the sheet to form a cylinder and overlaps the edges. Cemented seams are produced by passing the body blank edges over an open flame and applying special cement with wheel. Chilling rolls then solidify the cement and trimming knives remove cement between adjacent body blanks. The exposed edges are coated with lacquer. A thorough test is to be followed before the cemented side seams are used for cans under pressure.

4.1.2 Two-piece drawn and ironed cans:

These cans were developed in 1960's. This method of can manufacturing eradicates the side seam and separate bottom. The two-piece can body has an integral side and bottom and is made in a process that thins the sidewall while maintaining the thickness of the bottom. The widest use of these is in the beer and soft drink markets. To make a D&I can, a disc of metal sheet is formed into a shallow cup with a die. The cup is then pushed through several dies, each slightly smaller than the previous one, so that the sidewalls are stretched and thinned. Since the cup is held on the original punch, the inside dimension remains constant during this process. Starting with the plate thickness of 292 µm, the sidewalls are reduced to 97µm, while the bottom thickness remains same. This process of pushing the cup through progressively smaller die rings is termed as the ironing of sidewall. As the walls are ironed, the bottom is domed to provide strength and stability. The maximum ratio of height to diameter is 2:1. The can bodies are then cut to length and cleaned in preparation for coating inside and out. The can is then necked at the top and flanged to receive a top. The necking in produced a can with a narrower top thereby saving material. After leak test the cans are prepared for filling.

4.1.3 Two-piece drawn and redrawn cans:

In D&R method the cup is pushed through each-succeeding die. The gauge of the bottom and the sidewall of container remains essentially the same as the starting gauge but the inner dimensions of the cup becomes smaller. One or more punching operation may be used depending upon the depth of the can to be produced. These subsequent drawings or "redrawing" can be done once or twice. After drawing and redrawing, the can body is necked in at the bottom to permit easy stacking and incrusted in narrow bands to provide extra side wall strength for vacuum packaging.

While coatings will not adhere to D&I cans during production and must be applied to after the can body is formed, they may be applied to the flat can stock in the D&R process prior to drawing. A typical can, eg. Fruits & vegetable would start with steel having 184.6 µm gauge and end up with a side wall of 179.5 µm. The maximum ratio of height to diameter is about 1.5:1.

4.2 Non-round Cross Section Containers

Non-round cross section containers are typically used for fish and meats that are heat processed, as well as for products such as edible oils, which do not need to be processed. Open trays of round or non-round section are used for baked food products or with lids as take away food containers.

5. CLOSURE SYSTEMS

Closure systems for food and drink cans are by necessity very different in their mode of operation. Food cans require an aperture with either total or virtually full internal diameter of the container through which to remove the product, whereas the aperture for drink cans is designed to suit the method of consumption. Historically, food cans have required a can-opening tool to remove the plain lid. In more recent years, full aperture easy-open ends have been developed based on designs originally used for drink products. Whether plain or easy-open ends are used, the end panel for virtually all food and drink cans is mechanically seamed-on to produce a double seam that is capable of withstanding all the heat-processing cycles in use.

5.1 Easy-open Ends:

Easy open ends could be a stay-on tab found on the beverage cans or a ring-pull ends which is found on pet food or heat sealable flexible membrane. The bevcan end is a tab less design with a raised conical profile and a central 19.1 mm pour spout. It is opened by pressing downward a circular panel which pops inward without leaving any hazardous edges. The recent advancement in the easy open membrane lids, which simply peel away and often are teamed with a friction fit plastic lid for protection in the distribution chain.

5.2 Threaded Closures:

Screw-top cans are containers with threaded closures. A wide variety of threaded spouts and applicators have been available. A closure could be specified by the size of the outside of the threads on the container. There are no industry standards for threaded profiles, 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.

5.3 Slip Cover Closures:

Shallow cans with slip covers are made by blanking and drawing metal plate to the proper size and curling the edge. This category of closures includes simple reclosure type; firm reclosure type or friction closure type. There are still markets for highly decorated metal boxes, although the uses of these slip cover containers have greatly decreased due to the labour intensive cost of making these cans has soared and other types of mass-produced containers have developed.

6. CAN MATERIALS

Cans are made from either aluminium or steel. The steel can be chrome plated or laminated. The commonly called tin can is a misnomer. The sheet of these cans have only a thin coating of tin either on one side or on both sides.

6.1 Aluminium:

The composition of aluminium alloys for rigid containers varies according to the intended use, with up to 5 % magnesium, 1.5 % manganese and traces of iron, silicon, zinc, copper and titanium. As forming characteristics and resistance to corrosion improve, yield strength usually goes down and heavier gauges are required to have the same strength.

Aluminium alloys or tempers commonly used are: a fully hard material such as 3004 H-19 and a softer one such as 5052 H-34. Where 3004 or 5052 denote the aluminium alloy sheet and H-19, H-34 denotes the tempering. The hard tempered alloy H-19 allows the very thin gauges which make the container bodies economical. Shallow-drawn parts, such as can ends, use alloys with less ductility and medium temper of H-34 for average conditions.

6.2 Steel:

Ferrous metal used in fabricating cans include base steel or "black plate", tin-free steel which has thin coat of electroplated chromium and tin plate which has a thin coat of electroplated Grade-A commercially pure tin. Steel that has completed the tempering process is called 'black-plate'. Traditionally, it is used for spice containers and a number of industrial-packaging applications. It also forms the base of tin plate and electroplated chromium steel. Ferrous materials are used for ends and bodies in both two-piece and three-piece technologies.

An electrochemical passivation treatment, usually with sodium dichromate, stabilizes the surface and adds a thin film of metallic chrome to enhance the corrosion protection. Although the tin coating is only about 0.3 µm thick, it resists the corrosion not only by the protective layer of tin on its surface but also a cathodic reaction that minimizes oxidation at any pin holes or base spots. Tin coating also prevents the iron from being dissolved in certain beverages and food products.

6.3 Can Linings and Lacquers:

Metals used in can packaging often do not provide corrosion resistance, surface abrasion resistance and product-container compatibility. As a result, a variety of lacquers and lining materials have been developed to protect outer and inner surfaces and are also known as enamels. These are usually applied by roller or spray to flat sheet or coil and cured by oven or ultraviolet-light curing process. The enamels protect the surface of can by serving as a barrier to gases, liquid and ions. Enamels generally are specified in terms of mg/in^2.

7. APPLICATIONS

There are three major markets for metal cans; beverages like beer and soft drinks; food and non-food, comprising such products as paints, chemicals, etc.

7.1 Beverage Cans:

The beverage can market has been the fastest growing segment of the industry. Two-piece cans are predominant in the beverages as they are well suited to long production runs with infrequent label changes. Majority of market uses aluminium in manufacture of two-piece beverage cans, though in some European countries steel is still in use.

Aluminium cans manufactured by D&I process are extensively used for pasteurized beverages such as beer and soft drinks. Beer contains carbonic gas and when it is pasteurized after sealing the internal pressure may rise to ten times the pressure in food cans. The beer can therefore has to be designed to contain pressures up to 7 kg/cm^2. Due to their lighter weight per cm^2, aluminium cans reduce transportation cost. Remelting of aluminium cans to make aluminium slabs requires only five percent of the energy used to make virgin metal from bauxite ore. Thus the economics of recycling of aluminium cans have become quite favourable. It helps control the costs of materials and clearly favours the aluminium beverage package.

7.2 Food cans:

Food cans are manufactured in a greater variety of sizes and shapes than beverage cans and are generally produced in shorter production runs with frequent change over between sizes and labels. Both three piece welded cans and two piece steel cans are commonly used. The welding process produces a high-integrity three-piece can that is lead free. Welding technology provides the flexibility to run various specifications. Two-piece cans, which eliminate the side seam, are well suited to short sizes but tend to use more metal in taller sizes.

Shallow drawn aluminium cans are used extensively for processed foods such as vegetables, certain meat products, fillets of fish and various sauces. Deeper cans drawn and ironed are used for vegetables in brine or sauces, soups. Crabs and lobsters packed in aluminium cans do not require parchment lining to avoid discoloration of the product. Tomato sauce and mustard sauce are corrosive products, so the foods prepared in them, if to be packed in aluminium can should not exceed total 3% acidity, expressed as acetic acid. Other fresh foods packed in D&R cans include meat, boned chicken, etc.

A few products like roasted coffee, milk powder are canned in dry state. Heat processing and canning in such cases prevents loss of volatile, and moisture pick-up by hygroscopic powders, etc. Dry packed foods may be hermetically packed under vacuum or packed in an inert gas like nitrogen. Aluminium cans have also been developed for packaging of high sugar products. The shelf life of various food products packed in lacquered cans have been reported to vary from about one year for beer to more than seven years for carrots and peas.

8. Conclusion

Competition among metal, glass and plastic packaging products will continue to be a major force in overall container industry. Metal cans have been able to maintain a large share of the market owing to technological advances permitting efficient high speed operation and conservation of materials and energy.

Recent innovations in the design and manufacture of metal packaging for food products include: large opening stay-on-tab ends for drink cans, widgets to provide a foam head to beer and chilled coffee, self-heating and self-chilling drink cans, full aperture food can ends which are easier to open, square section processed food cans for more efficient shelf storage, peelable membrane ends for processed food cans, two-piece draw and wall iron as well as two-piece draw redraw cans made from steel with plastic extrusion coatings.

The prime purpose of packaging in a metal container is the physical and chemical protection of the product to be marketed. A perfect lacquered can is an ideal container for food with respect to all these. This will ensure that metals will continue to have an extremely important part to play in the cost efficient packaging of foods for short or long term ambient storage conditions. The inherent strength of metal containers and the fact that they are impervious to light contribute to a high level of protection for the contained product over long shelf life periods.

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Paper No.: 12
Paper Title: FOOD PACKAGING TECHNOLOGY
Module – 05: Paper and Paper based Packaging Materials

1. INTRODUCTION:

Paper and paper based materials are the oldest and most versatile packaging materials available on the market today. They are ironic material: they can be permanent or temporary, gentle or strong, cheap or expensive, in plenty or limited. They can be preserved in a museum or thrown away. They are made and used by the millions of tonnes or may be so rare that only a few tonnes of hand-made paper are produced in a year. Paper and board, alone or associated with other materials, has been used in food packaging or food contact for many years. A particular effort for alteration to the environmental concerns and the users' needs was made at the same time as the use of paper and board was increasing. Paper and board is indeed an essential part of our lives and satisfies many human needs. We use it to store and communicate information (newspapers, books, documents and writing paper), for cultural and artistic purposes, to transport and protect goods (packaging, sacks, liquid packaging board), and for personal hygiene (tissues, napkins, nappies, etc.).

2. WHAT IS PAPER?

Paper is made from cellulose fibres, which are obtained from trees, recovered papers and annual plant fibres like cereal straws. Today about 97 per cent of the world's paper and board is made from wood-pulp, and about 85 per cent of the wood-pulp used is from spruces, firs and pines. Nowadays, hardwoods such as birch, aspen and other hardwoods occurring in temperate climates are used as an ideal raw material for processing into fluting for corrugated cases as well as printing and writing papers, while eucalyptus, originally occurring in Australia and New Zealand, has been successfully cultivated in other warm climates as raw material for high-quality pulp suitable for a wide range of papers. Nonetheless, softwoods offer longer fibres (average 3 mm compared with 1 mm for hardwoods) and continue to be used for papers requiring the highest strength characteristics.

Chemically pure cellulose consists of long, ribbon-like molecules made up of smaller glucose units. The glucose units are formed from atoms of carbon, hydrogen and oxygen. These molecules are held together side-by-side by hydrogen bonds to form “sheets”, which in turn are piled together in tightly packed layers to form “microfibrils”. The microfibrils group themselves in bundles, and groups of these bundles form the paper fibre. Paper is called board when it is heavier than 224 g/m^2. The demands placed on the form of paper and board vary widely with the intended use but some are common to all grades, i.e., the paper must be strong enough to fulfil its technical function and also be able to be printed upon in a way that makes it striking to the customer. Paper and board can be used in contact with food in many different ways, either directly or indirectly, and either singly or laminated with other materials such as plastic or metal foil. In the latter case, so-called "functional barriers" are aimed at suppressing any substance transfer between food and the base paper material.

3. MANUFACTURE OF PAPER AND BOARD

Paper and board has a long history, beginning with the ancient Chinese and continuing to the present day. While hand-made methods dominated for thousands of years, paper production became industrialised during the 19th century. The first machine to manufacture paper continuously was invented by the Frenchman Louis-Nicolas Robert in 1799. Originally intended purely for writing and printing purposes, a wide variety of paper grades and uses are now available to the consumer. Each paper or board grade is produced on equipment tailored for this particular grade and mill. Production processes are optimised for each grade. There are many variables: raw material composition (mixture of chemical softwood and hardwood pulp, mechanical pulp, recovered paper, fillers, pigments, additives, etc.), machine size (width, speed), type of production equipment, and automation level.

Paper and board production involves two steps. First, the fibres need to be produced. This is done in a pulp mill where pulp is produced using chemical or/and mechanical processes. Pulp production can be integrated with paper production, or the pulp can be produced in a separate pulp mill. The paper itself is then produced on a paper machine from a mixture of fibres, chemicals and additives.

All paper and board machines are based on a similar basic process. There are seven distinct sections: head box, wire section (wet end), press section, drier section, size press, calender and reel-up.

3.1 The preparation and the cleansing of the pulp:

This untwists the fibers. Beating is a mechanical treatment intended for swelling, fibrillating and shortening the fibres. The result is a better sheet formation and the development of paper's mechanical properties.

3.2 Before sending to the paper machine:

The pulp is initially purified, diluted and air bubbles are eliminated. Sometimes pulp is also bleached if made from recycled paper.

3.3 The wet-end part:

Raw material fibres and chemicals (and 99% of the water) are pumped to the head box, which feeds the stock evenly onto the wire section. This is a woven plastic mesh conveyor belt that can be 35 metres long and up to 10 metres wide. As the paper stock flows from the head box onto the wire, the water drains away through the mesh leaving small fibres as a mat on top of the mesh. The paper machine can travel at speeds of up to 2000 m/minute and by the time the paper stock has travelled half way down the wire, a high percentage of water has drained away. By the time the thin mat of fibres has reached the end of the wire section, it has become a sheet of paper, although very moist and of little strength.

3.4 The press section:

This section consists of a number of sets of felts and heavy cylinders through which the moist paper web passes. More water is pressed out to felts and drawn away by suction. Pressure binds the fibres together and consolidates the web.

3.5 Dryer:

This section consists of a large number of steam-heated drying cylinders which have a temperature of slightly over 100°C. Synthetic drier fabrics carry the paper web round the cylinders until the paper is dry.

3.6 Coating/Calendering:

In many applications, the surface of the sheet needs improvement in order that any characters imposed on the sheet be legible. This is achieved by calendering, a process which reorients the surface fibres in the base sheet of paper (or the coating applied to the surface) by the use of pressure. This serves to smooth the surface, control surface texture and develop a glossy finish. Such papers are known as machine finished.

3.7 Finishing:

At the end of the drying process, the sheet is smoothed using an "ironing" method, which consists of hot polished iron rollers mounted in pairs with synthetic material rollers, one above the other. This also helps to consolidate, polish and glaze the surface of the paper: the characteristics of the surface of the sheet are improved.

3.8 Shipping:

Still travelling at very high speeds, the paper comes off the machine ready for reeling up into large reels (called parent reels), which can be cut or slit into smaller ones, according to customer requirements. These large reels are produced and changed without any interruption of the production process.

3.9 Quality control:

Sensors and computers verify parameters such as the production speed, the pressure, and the resistance at every step of the process to ensure that the paper or board is of a consistently high quality. Moreover, for food contact applications, microbiological, chemical and organoleptic controls have to be carried out.

A board machine often has several formation devices in the wet end producing a multiply sheet, combined on the forming table and press. Basis weight of the boards can be as high as 500 g/m^2, whereas the printing and writing papers are usually 40-120 g/m^2.

Paper and board machines are each different – the size of the production capacity and technology varies. Each one is tailored to the specification of the paper mill.

4. RECOVERED PAPER AND BOARD

Recovered or recycled paper is an important raw material in terms of volume and utilisation for the paper industry in many countries. The recycling of paper is an example of sustainable use of resources. Although recycling is both economically and ecologically sound, recovered paper cannot be used in all paper grades. The final production process for recycled paper is the same as the process for paper made from primary fibres. The main difference is that recovered paper fibres have already been used, so that non-fibre material, will have to be removed.

The major steps in the recycling process are:

1. **Collection and Transportation:** Recovered paper is sorted, graded, formed into bales and delivered to a paper mill.
2. **Repulping and Screening:** After reaching the paper mill, recovered paper is mixed with water and chemicals, which separates the paper into individual fibres.
3. **Cleaning:** The pulp mix is diluted with water and passes through a system of centrifugal cleaning equipment and screens. The pulp is filtered and screened through a number of cycles to make it more appropriate for papermaking. This is done to remove large contaminants like wood, plastic, stones, glass and paper clips, along with small contaminants like string, glue and other sticky materials. Pulp is cleaned in a large spinning cylinder and the heavy contaminants move to the outside of the cylinder and are removed.
4. **De-inking:** For certain uses (e.g. for the production of graphic, sanitary and domestic papers but rarely for manufacture of packaging materials) and for certain types of recovered papers (e.g. newspapers and magazines), the fibres have to be de-inked. The deinking process can be carried out by flotation, with or without washing, with or without kneading, with or without bleaching.

The finished recycled pulp is now ready to be made into paper and is either sent on a mile-long conveyor to the mill for papermaking, or is formed into sheets of pulp for shipment and sale. Depending on the grade of paper being produced, quantities of virgin pulp from sustainable sources may be added. Some papers, such as newsprint and corrugated materials, can be made from almost 100% recycled paper. Once the paper is used, it can be recycled and the process starts again. Individual fibres will gradually be degraded in the process so a continuous addition of new fibres is necessary to sustain the recycling cycle.

There are different grades of recovered paper and board to satisfy the needs of different producers according to specifications. More than 50 grades of recovered paper and board are defined in the European List of Standard Grades of Recovered Paper and Boards.

They can be described as follows:

1. **Low grades** (mixed papers, old corrugated containers, board, etc.): These constitute the main part of the recovered paper consumed. These are used to produce secondary packaging papers and boards, and are not intended to be in direct contact with food
2. **De-inking grades** (newspapers and magazines, graphic papers, etc.): They are usually also considered as low grades because they need extensive recycling treatments. These are for graphic and sanitary papers.
3. **High grades** (scraps, sheets, print offcuts, etc.): They require little or no cleaning. They can be used for the production of any paper product as pulp substitute. They may therefore be suitable for food contact packaging.

5.0 TYPES OF PAPER

Paper is divided into two broad categories: fine papers, generally made of bleached pulp, and typically used for writing paper, bond, ledger, book and cover papers, and coarse papers, generally made of unbleached kraft softwood pulps and used for packaging.

5.1 Kraft Paper

This is typically a coarse paper with exceptional strength, often made on a fourdrinier machine and then either machine-glazed on a Yankee dryer or machine-finished on a calender. It is sometimes made with no calendering so that when it is converted into bags, the rough surface will prevent them from sliding over one another when stacked on pallets.

5.2 Bleached Paper

These are manufactured from pulps which are relatively white, bright and soft and receptive to the special chemicals necessary to develop many functional properties. They are generally more expensive and weaker than unbleached papers. Their aesthetic appeal is frequently improved by clay coating on one or both sides.

5.3 Greaseproof Paper

This is a translucent, machine-finished paper which has been hydrated to give oil and grease resistance. Prolonged beating or mechanical refining is used to fibrillate and break the cellulose fibres which absorb so much water that they become superficially gelatinized and sticky. This physical phenomenon is called hydration and results in consolidation of the web in the paper machine with many of the interstitial spaces filled in. The satisfactory performance of greaseproof papers depends on the extent to which the pores have been closed. Provided that there are few interconnecting pores between the fibres, the passage of liquids is difficult. However, they are not strictly greaseproof since oils and fats will penetrate them after a sufficient interval of time. Despite this, they are often used for packaging butter and similar fatty foods since they resist the penetration of fat for a reasonable period.

5.4 Glassine Paper

Glassine paper derives its name from its glassy, smooth surface, high density and transparency. It is produced by further treating greaseproof paper in a supercalender where is it carefully dampened with water and run through a set of steam-heated rollers. This results in such intimate inter-fibre hydrogen bonding that the refractive index of the glassine paper approaches the 1.02 value of amorphous cellulose, indicating that very few pores or other fibre/air interfaces exist for scattering light or allowing liquid penetration. The transparency can vary widely depending on the degree of hydration of the pulp and the basis weight of the paper. It is frequently plasticized to increase its toughness.

5.5 Vegetable Parchment

Vegetable parchment takes its name from its physical similarity to animal parchment which is made from animal skins. The process for producing parchment paper was developed in the 1850s, and involves passing a web of high-quality, unsized chemical pulp through a bath of concentrated sulphuric acid. The cellulosic fibres swell and partially dissolve, filling the spaces between the fibres and resulting in extensive hydrogen bonding. Thorough washing in water, followed by drying on conventional papermaking dryers, causes reprecipitation and consolidation of the network, resulting in a paper that is stronger wet than dry (it has excellent wet strength, even in boiling water), free of lint, odour and taste, and resistant to grease and oils. Unless specially coated or of a heavy weight, it is not a good barrier for gases.

Because of its grease resistance and wet strength, it strips away easily from food material without defibering, thus finding use as an inter-leaver between slices of food such as meat or pastry. Labels and inserts in products with high oil or grease content are frequently made from parchment. It can be treated with mold inhibitors and used to wrap foods such as cheese.

5.6 Waxed Paper

Waxed papers provide a barrier against penetration of liquids and vapours. Many base papers are suitable for waxing, including greaseproof and glassine papers. The major types are wet-waxed, dry-waxed and wax-laminated. Wax-sized papers, in which the wax is added at the beater during the papermaking process, have the least amount of wax and therefore give the least amount of protection.

Wet-waxed papers have a continuous surface film on one or both sides, achieved by shock-chilling the waxed web immediately after application of the wax. This also imparts a high degree of gloss on the coated surface. Dry-waxed papers are produced using heated rolls and do not have a continuous film on the surfaces. Consequently, exposed fibres act as wicks and transport moisture into the paper. Wax-laminated papers are bonded with a continuous film of wax which acts as an adhesive. The primary purpose of the wax is to provide a moisture barrier and a heat sealable laminant. Often special resins or plastic polymers are added to the wax to improve adhesion and low temperature performance, and to prevent cracking as a result of folding and bending of the paper.

6. FOOD PACKAGING APPLICATIONS OF PAPER & BOARDS

Paper and board comes in a variety of forms for applications:

1. **Paper packaging:** Natural or bleached, rubbed, coated or associated with other materials, paper can be found in the shape of bags e.g. for fruits and vegetables, vegetable parchment paper.

2. **Folding box board:** It is often referred to as carton board, it may be single or multi-ply, wood coloured or grey, coated or non-coated, and it can present various properties like barrier to grease, humidity, gas and it can be found in the shape of pastry boxes or container. It is mainly used in cartons for consumer products such as frozen food and for liquid containers.
3. **Corrugated board:** It is brown and white, of low grammage or high density, resistant to bursting, to humidity or to compression, it can be found in different shapes such as showcases for use in stores, or small boxes for mass-market products. Corrugated cases constitute the highest volume of paper and board for food contact applications.

For food contact applications, the package has to be strong enough to protect the food. It is generally printed to ensure its attractiveness to the customer because it is part of the food delivery structure. To a limited extent, some barrier properties are expected, to protect the food against degradation by the external environment. Specific barrier properties may be obtained with dedicated chemical treatments or through lamination with other materials such as metal or plastic.

There has been a significant increase in the use of paper and paper based packaging in the past 50 years for many reasons.

1. It is robust and flexible – corrugated board can be used to protect delicate porcelain or large electrical items, but also delicate fruits and vegetables.
2. It is practical – cartons can be delivered flat to the packager, reducing space and transport costs.
3. It can be easily recycled.
4. It is made from renewable materials, recovered paper and wood pulp.

7. Conclusion

Paper is a very versatile material. It is produced from cellulosic, naturally renewable fibres. It is therefore considered as an environmentally friendly material, being easily recycled, composted or incinerated after use. It may be used in food packaging applications within a wide range of grammages, being designed as wrapping paper, folding box board or corrugated board, for direct or indirect contact, i.e. as primary, secondary or tertiary packaging. Other paper grades, such as tissue paper, may be used in occasional contact with foodstuffs.

When paper and paper based products are intended, or likely, to come into contact with food, manufacturers follow relevant and acknowledged regulations and guidelines to design manufacturing processes and recipes, and ensure consumer safety.

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Paper No.: 12

Paper Title: Food packaging technology

Module – 10: Structure and properties of plastic polymers

10.1 Introduction

Different types of plastics are used for different purposes based on the characteristics of plastics and type of product. Some of the plastics are discussed hereunder that can be used in food packaging.

10.2 Polyethylene (PE)

PE is structurally the simplest plastic and is made by addition polymerization of ethylene gas in a high temperature and pressure reactor. Low, medium and high density resins are produced, depending on the conditions (temperature, pressure and catalyst) of polymerization. The processing conditions control the degree of branching in the polymer chain and therefore the density and other properties of films and other types of packaging. Polyethylenes are readily heat sealable. They can be made into strong, tough films, with good moisture and water vapour barrier properties. They are not high barrier to oils and fats or gases such as carbon dioxide and oxygen compared with other plastics, although barrier properties increase with density. The heat resistance is lower than that of other plastics used in packaging, with a melting point of around 120°C. The melting point increases as the density increases.

PE was first used as an insulator in the 1940s. PE films are highly susceptible of generating a static charge and need to have antistatic, slip agents and anti-blocking compounds added to the resin to assist film manufacturing, conversion and use. It is the most widely used and is cost effective.

10.2.1 Low density polyethylene (LDPE)

LDPE is easily extruded as a tube and blown to stretch it by a factor of three times the original area. It is commonly manufactured around 30 µm (20 or 25 µm is also possible) within a density range 0.910–0.925 g cm^{-3}.

The films can be coloured by blending pigment with the polymer prior to extrusion where extruders have more than one die. Two or more layers of the same material or coextruded films comprised of layers of different plastic materials can also be produced. With three extruders, it is possible to produce a film where, for example, a moisture-sensitive polymer, EVOH, is sandwiched between protective layers of PE. EVOH provides a gas and odour barrier, and the PE offers good heat-sealing properties and a substrate for printing.

PE film melts at relatively low temperatures and welds to itself when cut with a hot wire, or blade, to form effective seals. For packaging, it is possible to use either premade bags or form/fill/seal machines using flat film in reel form. A major use of white pigmented LDPE film is for making bags for holding frozen vegetables.

By laminating to other substrates with adhesives, or extruding the PE polymer onto another material, or web, it is possible to make strong sachets, pouches and bags with good seal integrity, as the PE flows to fill holes in the sealing area or around contaminants in the seal.

10.2.2 Linear low-density polyethylene (LLDPE)

LLDPE film has a density range similar to that of LDPE. It has short side chain branching and is superior to LDPE in most properties such as tensile and impact strength and also in puncture resistance. A major use has been the pillow pack for liquid milk and other liquid foods.

10.2.3 Medium-density polyethylene (MDPE)

MDPE film is mechanically stronger than LDPE and therefore used in more demanding situations. LDPE is coextruded with MDPE to combine the good sealability of LDPE with the toughness and puncture resistance of MDPE, e.g. for the inner extrusion coating of sachets for dehydrated soup mixes.

10.2.4 High-density polyethylene (HDPE)

HDPE is the toughest grade and is extruded in the thinnest gauges. This film is used for boil-in-the-bag applications. To improve heat sealability, HDPE can be coextruded with LDPE to achieve peelable seals where the polymer layers can be made to separate easily at the interface of the co-extrusion. HDPE film is available with either TD monoaxial orientation or biaxial orientation.

HDPE is injection moulded for closures, crates, pallets and drums, and rotationally moulded for intermediate bulk containers (IBCs). A major application of HDPE is for blow moulded milk containers with a capacity 0.5–3 l.

10.3 Polypropylene (PP)

PP is an addition polymer of propylene formed under heat and pressure using Zieger-Natta type catalysts to produce a linear polymer. PP is a harder and denser resin than PE and more transparent in its natural form. The usage of PP developed from the 1950s onwards. PP has the lowest density and highest melting point of all the high volume usage thermoplastics and has a relatively low cost. It can be processed in many ways and has many food packaging applications in both flexible film and rigid form.

The high melting point of PP (160°C) makes it suitable for applications where thermal resistance is needed, for example in hot filling and microwave packaging. PP may be extrusion laminated to PET or other high-temperature resistant films to produce heat-sealable webs which can withstand temperatures of up to 115–130°C, for sterilizing and use in retort pouches.

PP is chemically inert and resistant to most commonly found chemicals, both organic and inorganic. It is a barrier to water vapour and has oil and fat resistance.

Orientation increases the versatility of PP film. Oriented PP (OPP) or biaxially oriented PP (BOPP) film was the first plastic film to successfully replace regenerated cellulose film (RCF) in major packaging applications such as biscuit packing. Acrylic-coated OPP has good runnability, including heat sealing, on packing machines, designed for RCF, though improved temperature control of the heat-sealing equipment is required.

OPP film is produced in widths of up to 10 m or more to achieve cost-effective production. The limiting factors in production are either extrusion capacity for the thicker films or winding speed for the very thin films.

The range of food products packed in PP films include biscuits, crisps (chips) and snack foods, chocolate and sugar confectionery, ice cream and frozen food, tea and coffee. Metalized PP film can be used for snacks and crisps (chips) where either a higher barrier or longer shelf life is required.

Paperboard can be extrusion coated with PP for use as frozen or chilled food trays which can be heated in microwave and steam-heated ovens. Major food applications of PP are for injection-moulded pots and tubs for yoghurt, ice cream, butter and margarine. It is also blow-moulded for bottles and wide mouth jars. PP is widely used for the injection moulding of closures for bottles and jars.

It is used in thermoforming from PP sheet, as a monolayer, for many food products such as snacks, biscuits, cheese and sauces. In co-extrusions with PS, EVOH and PE it is used for the packaging of several types of food product including those packed aseptically, by hot filling, and in microwaveable and retortable packs.

10.4 Polyethylene terephthalate (PET or PETE)

When terephthalic acid reacts with ethylene glycol and polymerises, the result is PET.

PET can be made into film by blowing or casting. It can be blow moulded, injection moulded, foamed, extrusion coated on paperboard and extruded as sheet for thermoforming. PET can be made into a biaxially oriented range of clear polyester films produced on essentially the same type of extrusion and Stenter-orienting equipment as OPP. Film thicknesses range from thinner than 12 µm for most polyester films to around 200 µm for laminated composites.

PET melts at 260°C, and due to the manufacturing conditions does not shrink below 180°C. Therefore, PET is ideal for high-temperature applications using steam sterilisation, boil-in-the-bag and for cooking or reheating in microwave or conventional radiant heat ovens. The film is also flexible in extremes of cold (−100°C). Heat-sealable versions are available, and it can also be laminated to PE to give good heat-sealing properties. Coating with PVdC give a good gas barrier and heat-sealing capability.

PET is a medium oxygen barrier but becomes a high barrier to oxygen and water vapour when metalized with aluminium. This is used for vacuumised coffee and bag-in-box liquids, where it is laminated with EVA on both sides to produce highly effective seals. It is also used in snack food flexible packaging for products with a high fat content requiring barriers to oxygen and ultra violet (UV) light. Metalized PET, either as a strip or as a flexible laminate, is used as a susceptor in microwaveable packaging.

Reverse printed PET film is used as the external ply on FFS pouches where it provides a heat-resistant surface for contact with the heat-sealing bars. The amorphous cast grades can be used as the bottom web in formed applications which are lidded with a heat-sealable grade of PET. These packs can be reheated in microwave and conventional ovens.

PET film is also used as the outer reverse-printed ply in retort pouches, providing strength and puncture resistance, where it is laminated with aluminium foil and either PP or HDPE. PET can be oxide coated with SiO_2 to improve the barrier, whilst remaining transparent, retortable and microwaveable.

Paperboard is extrusion coated with PET for use as ready meal trays which can be reheated in microwave or conventional radiant heat ovens, i.e. dual ovenable. The PET coated side of the paperboard is on the inside of the tray which is erected by corner heat sealing.

PET is the fastest growing plastic for food packaging applications as a result of its use in all sizes of carbonated soft drinks and mineral water bottles which are produced by injection stretch blow moulding. PET bottles are also used for edible oils, as an alternative to PVC.

10.5 Polycarbonate (PC)

PC is a polyester containing carbonate groups in its structure. It is formed by the polymerisation of the sodium salt of bisphenolic acid with phosgene. It is glass clear, heat resistant and very tough and durable. PC is mainly used as a glass replacement in processing equipment and for glazing applications. Its use in packaging is mainly for large, returnable/refillable 3–6 litre water bottles. It is used for sterilisable baby feeding bottles and as a replacement in food service. It has been used for returnable milk bottles, ovenable trays for frozen food and if coextruded with nylon could be used for carbonated drinks.

10.6 Ionomers

Ionomers are polymers formed from metallic salts of acid copolymers and possess interchange ionic cross-links which provide the characteristic properties of the family of plastics. The metallic ions can be zinc or sodium and the copolymer is based on ethylene and methacrylic acid. It is clear, tougher than PE, having high puncture strength, and has excellent oil and fat resistance. Hence, it is used for the packaging of products contain essential oils, in the aseptic liquid packaging of fruit juices in cartons, and fat containing products (e.g. snack foods) in sachets. It has excellent heat-sealing properties, leading to increased packing line speeds. It is used in the packaging of meat, poultry and cheese. It is particularly useful in packing product with sharp protrusions.

In food packaging, ionomer films, including coextruded films, are used in laminations and extrusion coatings in all the main types of flexible packaging.

These include:

- vertical and horizontal FFS
- vacuum and MAP packing
- four-side sealed pouches and twin-web pouches with one web thermoformed
- inner ply of paperboard composite cans, e.g. aluminium foil/ionomer
- diaphragm or membrane seals.

Ionomers are used in laminated and coated form with PET, PA, PP, PE, aluminium foil, paper and paperboard.

10.7 Ethylene vinyl acetate (EVA)

EVA is a copolymer of ethylene with vinyl acetate. It is similar to PE in many respects, and it is used, blended with PE, in several ways. The properties of the blend depend on the proportion of the vinyl acetate component. Generally, as the VA component increases, sealing temperature decreases and impact strength, low temperature flexibility, stress resistance and clarity increase. At a 4% level, it improves heat sealability, at 8% it increases toughness and elasticity, along with improved heat sealability, and at higher levels, the resultant film has good stretch wrapping properties. EVA with PVdC is a tough high-barrier film which is used in vacuum packing large meat cuts and with metalized PET for bag-in-box liners for wine.

Modified EVAs are available for use as peelable coatings on lidding materials such as aluminium foil, OPP, OPET and paper. They enable heat sealing, resulting in controllable heat seal strength for easy, clean peeling. These coatings will seal to both flexible and rigid PE, PP, PET, PS and PVC containers.

Modified EVAs are also used to create strong interlayer tie bonding between dissimilar materials, e.g. between PET and paper, LDPE and EVOH. EVA is also a major component of hot melt adhesives, frequently used in packaging machinery to erect and close packs, e.g. folding cartons and corrugated packaging.

10.8 Polyamide (PA)

PA are commonly known as nylon. They were initially used in textiles, but subsequently other important applications were developed including uses in packaging and engineering. Polyamide plastics are formed by a condensation reaction between a diamine and a diacid or a compound containing each functional group (amine). The different types of polyamide plastics are characterised by a number which relates to the number of carbon atoms in the originating monomer. It has mechanical and thermal properties similar to that of PET and therefore similar applications. PA resins can be used to make blown film, and they can be coextruded.

PA can be blended with PE, PET, EVA and EVOH. It can be blow moulded to make bottles and jars which are glass clear, low in weight and have a good resistance to impact.

Biaxially oriented PA film has high heat resistance and excellent resistance to stress cracking and puncture. It has good clarity and is easily thermoformed, giving a relatively deep draw. It provides a good flavour and odour barrier and is resistant to oil and fat. It has a high permeability to moisture vapour and is difficult to heat seal. These features can be overcome by PVdC coating. They can also be overcome by lamination or co-extrusion with polyethylene, and this structure is used as the bottom thermoformable web, i.e. deep drawn, for packing bacon and cheese in vacuum packs or in gas-flushed packs (MAP or modified atmosphere packaging). The film can also be metalized.

PA film is used in retortable packaging in structures such as PA/aluminium foil/PP. The film is non-whitening in retort processing. PA is relatively expensive compared with PE, but as it has superior properties, it is effective in low thicknesses.

10.9 Polyvinyl chloride (PVC)

If one of the hydrogen atoms in ethylene is replaced with a chlorine atom, the resultant molecule is called vinyl chloride monomer (VCM). Addition polymerization of vinyl chloride produces PVC.

Rigid Unplasticized PVC (UPVC) is used for transparent or coloured compartmented trays for chocolate assortments and biscuits. It is used with MAP for thermoformed trays to pack salads, sandwiches and cooked meats.

Most PVC films are produced by extrusion, using the bubble process. It can be oriented to produce film with a high degree of shrinkability. Up to 50% shrinkage is possible at quite low temperatures. The film releases the lowest energy of the commonly used plastic films when it is heat shrunk around products. It is plasticised, and the high stretch and cling make it suitable for overwrapping fresh produce, e.g. apples and meat in rigid trays using semi-automatic and manual methods.

Printed PVC film is used for heat-shrinkable sleeve labels for plastic and glass containers. It is also used for tamper-evident shrink bands. Thicker grades are thermoformed to make trays which, after filling, are lidded with a heat seal-compatible top web.

PVC has excellent resistance to fat and oil. It is used in the form of blow moulded bottles for vegetable oil and fruit drinks. It has good clarity. As a film, it is tough, with high elongation, though with relatively low tensile and tear strength. The moisture vapour transmission rate is relatively high, though adequate for the packaging of mineral water, fruit juice and fruit drinks in bottles. PVC softens, depending on its composition, at relatively low temperatures (80–95°C). PVC easily seals to itself with heat, but heat sealing with a hot wire has the disadvantage of producing HCl gas.

The permeability to water vapour and gases depends on the amount of plasticizer used in manufacture. UPVC is a good gas and water vapour barrier, but these properties decrease with increasing plasticiser content. There are grades which are used to wrap fresh meat and fresh produce, where a good barrier to moisture vapour retards weight loss, but the permeability to oxygen allows the product to *breathe*. This allows fresh meat to retain its red colour and products such as fruits, vegetables and salads to stay fresh longer by reducing the rate of respiration, especially when packed in a modified atmosphere (MAP).

10.10 Polyvinylidene chloride (PVdC)

PVdC is a copolymer of vinyl chloride and vinylidene chloride – the latter forms when two hydrogen atoms in ethylene are replaced by chlorine atoms.

PVdC is heat sealable and is an excellent barrier to water vapour and gases and to fatty and oily products. As a result of the high gas and odour barrier, it is used to protect flavour and aroma sensitive foods from both loss of flavour and ingress of volatile contaminants. It is used in flexible packaging in several ways:

Monolayer film: A well-known application is the Cryovac range introduced by W.R. Grace and now operated by the Sealed Air Corporation. This includes poultry packing where hot water shrinkable bags are used to achieve a tight wrap around the product. The film can be used in the form of sachets but is less likely to be cost effective compared with other plastic films – some of which may incorporate PVdC as a coating. An interesting use is as sausage and chubb casing.

Coextrusions: PVdC is often used in coextrusion, where, today, extruders incorporate three, five and even seven extrusion layers to meet product protection and packaging machinery needs cost effectively.

Coatings. These may be applied using solutions in either organic solvents or aqueous dispersions to plastic films such as BOPP and PET, to RCF and to paper and paperboard.

Hence, PVdC is a widely used component in the packaging of cured meats, cheese, snack foods, tea, coffee and confectionery. It is used in hot filling, retorting, low-temperature storage and MAP as well as ambient filling and distribution in a wide range of pack shapes.

10.11 Polystyrene (PS)

PS is an addition polymer of styrene, a vinyl compound where a hydrogen atom is replaced with a benzene ring. PS has many packaging uses and can be extruded as a monolayer plastic film, coextruded as a thermoformable plastic sheet, injection moulded and foamed to give a range of pack types. It is also copolymerised to extend its properties.

It is less well known as an oriented plastic film, though the film has interesting properties. It has high transparency (clarity). It is stiff, with a characteristic crinkle, suggesting freshness, and has a deadfold property. The clear film is used for carton windows, and white pigmented film is used for labels. The film is printable. It has a low barrier to moisture vapour and common gases, making it suitable for packaging products, such as fresh produce, which need to breathe.

PS is easily processed by foaming to produce a rigid lightweight material which has good impact protection and thermal insulation properties. It is used in two ways. The blown foam can be extruded as a sheet which can be thermoformed to make trays for meat and fish, egg cartons, a variety of fast food packs such as the clam shell-shaped container, as well as cups and tubs. Thin sheets can be used as a label stock. The foam can also be produced in pellet or bead form which can then be moulded with heat and pressure. This is known as expanded polystyrene or EPS. It can be used as a transit case for fresh fish, with thick walls for insulation.

PS so far described is general purpose polystyrene. The main disadvantage as a rigid or semi-rigid container is the fact that it is brittle. This can be overcome by blending with styrene butadiene copolymer, SB or SBC, an elastomeric polymer. The blend is known as high-impact polystyrene or HIPS.

Blending produces a tougher material. It is translucent and is often used in a white pigmented form. The sheet can be thermoformed for short shelf life dairy products.

HIPS is also used in multilayer sheet extrusion with a variety of other polymers, each of which contributes to the protection and application needs of the product concerned. Other polymers which may be used in this way with HIPS include PE, PP, PET, PVdC and EVOH. The food products packed with these materials include dairy products such as cream and yoghurt-based desserts, UHT milk, cheese, butter, margarine, jam, fruit compote, fresh meat, pasta, salads etc. Many of these products are packed aseptically on thermoform, fill and seal machines.

10.12 Ethylene vinyl alcohol (EVOH)

EVOH is a copolymer of ethylene and vinyl alcohol. It is related to polyvinyl alcohol (PVOH), which is a water-soluble synthetic polymer with excellent film-forming, emulsifying and adhesive properties. It is a high-barrier material with respect to oil, grease, organic solvents and oxygen. It is moisture sensitive and, in film form, is water soluble. PVOH itself has packaging applications in film form but not in food products, and it is used as a coating for BOPP.

EVOH was developed to retain the high-barrier properties of PVOH. It is also an excellent barrier to oxygen and is resistant to the absorption and permeation of many products, especially those containing oil, fat and sensitive aromas and flavours. Though it is moisture sensitive to a much lesser degree than PVOH, it is still necessary to *bury* it in multilayered coextruded structures, such as film for flexible packaging, sheets for thermoforming and in blowmoulded bottles, so that it is not in contact with liquid.

The other polymers used depend on the application, i.e. the food product and type of pack. PS/EVOH/PS and PS/EVOH/PE sheets are used for processed cheese, pâtè, UHT milk and milk-based desserts and drinks. It is also used for MAP of fresh meat and for pasta, salads, coffee and hot filled processed cheese, including portion packed cheese and fruit compote.

A higher-barrier sheet can be constructed with PP/EVOH/PP for pasterizable and retortable products such as fruit, pâté, baby food, sauces like ketchup and ready meals, some of which are reheated by microwave. Coextruded film applications can involve EVOH with nylon, LLDPE and ionomer with food products such as bag-in-box wine, processed and fresh meat.

Extrusion lamination can involve EVOH with PET, LDPE and LLDPE for coffee, condiments and snacks. It is used with PET and PP for tray lidding material. Extrusion lamination of paperboard with EVOH and PE is used for aseptically packed UHT milk and fruit juices where the EVOH layer provides an oxygen barrier as a replacement for aluminium foil. In blow moulding, EVOH is used with PP for sauces, ketchup, mayonnaise and cooking oil and with HDPE for salad dressings and juices. Ketchup and mayonnaise bottles based on EVOH are squeezable.

Small tubes made by profile coextrusion are used for condiments by incorporating EVOH into structures with LDPE and LLDPE. EVOH is an important polymer in many processing applications providing protection for many types of food product.

10.13 Fluoropolymers

Fluoropolymers or fluoroplastics are high-performance polymers related to ethylene where some or all of the hydrogen atoms are replaced by fluorine, and in the packaging polymer a hydrogen is also replaced by a chlorine atom to produce polychlorotrifluoroethylene (PCTFE).

It has the highest water vapour barrier of all the commercially available packaging polymers, is a very good gas barrier and offers high resistance to most chemicals at low temperatures. In many applications, it is a suitable replacement for aluminium foil. It is available as a film or sheet. It is transparent, heat sealable and can be laminated, thermoformed, metalized and sterilized.

It is relatively expensive and is best known as a thermoformable blister pack material laminated with PVC for pharmaceutical tablets. Food packaging applications are possible but are not highlighted at the present time. Polytetrafluoroethylene (PTFE), better known as Teflon, is a high melting point, inert and waxy polymer. It is used in the form of tape and coatings on packaging machines to reduce adhesion, where that could be a problem, e.g. heat seal bars, and to reduce friction where packaging materials move over metal surfaces.

Paper No.: 12
Paper Title: FOOD PACKAGING TECHNOLOGY
Module – 9: Plastics as Packaging Material and Flexible Films

9.1 Introduction

Plastics are defined as organic macromolecular compounds obtained by polymerisation, polycondensation, polyaddition or any similar process from molecules with a lower molecular weight or by chemical alteration of natural macromolecular compounds.

Molecules with a lower molecular weight are known as monomers and the *macromolecular compounds* are known as polymers – a word derived from Greek, meaning *many parts.*

The first plastics were derivativeof natural raw materials (coal, oil and natural gas) in the first half of the 20th century. The most widely used plastic today, polyethylene, was invented in 1933 – it was used in packaging from the late 1940s onwards in the form of squeeze bottles, crates for fish replacing wooden boxes and film and extrusion coatings on paperboard for milk cartons.

Plastics can meet the needs of a wide temperature range, from frozen food processing (−40°C) and storage (−20°C) to the retort sterilization (121°C), and reheating of packaged food products by microwave(100°C) and radiant heat (200°C). Most packaging plastics are thermoplastic,which means that they can be softened and melted repeatedly when heated.This feature has several important implications for the use and performance ofplastics, as in the forming of containers, film manufacture and heat sealing property.

9.1.1 Advantages of plastics

Plastics are widely used for packaging materials because of following advantages:

- Flowability and mouldability under certain conditions
- Almost inert
- Cost effectiveness
- Lightweight
- Transparent
- Ease of giving colour
- Ease of heat sealing
- Heat resistance and barrier.

9.1.2 Use of plastics in food packaging

Plastics are used as containers, container components and flexible packaging.In usage, by weight, they are the second most widely used type of packagingand first in terms of value. Examples are as follows:

- Rigid plastic containers such as bottles, jars, pots, tubs and trays etc.
- Flexible plastic films in the form of bags, sachets, pouches and heat-sealable flexible lidding materials
- Plastics combined with paperboard in liquid packaging cartons
- Expanded or foamed plastic for uses where some form of insulation, rigidity and the ability to survive compression is required

- Plastic lids and caps and the lining used in such closures
- Diaphragms on plastic and glass jars to provide product protection and tamper indication
- Plastic bands to provide external tamper evidence
- Pouring and dispensing devices
- To collate and group individual packs in multipacks, e.g. Hi-cone rings for cans of beer, trays for jars of sugar preserves etc.
- Plastic films used in cling, stretch and shrink wrapping
- Films used as labels for bottles and jars, as flat glued labels or heatshrinkable sleeves
- Components of coatings, adhesives and inks.

9.1.3 Types of plastics used in food packaging

The following are the types of plastics used in food-packaging

- Polyethylene (PE)
- Polypropylene (PP)
- Polyesters (PET, PEN, PC) (PET is also referred to as PETE)
- Ionomers
- Ethylene vinyl acetate (EVA)
- Polyamides (PA)
- Polyvinyl chloride (PVC)
- Polyvinylidene chloride (pvdc)
- Polystyrene (PS)
- Styrene butadiene (SB)
- Acrylonitrile butadiene styrene (ABS)
- Ethylene vinyl alcohol (EVOH)
- Polymethyl pentene (TPX)
- High nitrile polymers (HNP)
- Fluoropolymers (PCTFE/PTFE)
- Cellulose-based materials
- Polyvinyl acetate (PVA)

PE constitutes the highest proportion of consumption as packaging material followed by PP, PET, PS (including expanded polystyrene or EPS) and PVC.

9.2 Manufacture of packaging film

The plastic raw material (resin) is in the form of pellets. Plastics in powder form are used in some processes. While some plastics are used to make coatings, adhesives or additives in other packaging related processes, the first major step in the conversion of plastic resin into films, sheets, containers etc., is to change the pellets from solid to liquid or molten phase in an extruder.

The plastic is melted by a combination of pressure, friction and heat. This is done by forcing the pellets along the barrel of an extruder using specially designed, polymer-specific, screw under controlled conditions that ensure the production of a homogeneous melt prior to extrusion.

The molten plastic is then forced througha narrow slot or dies to manufacture film and sheet while it is forced into shape using a mold to manufacture rigid packaging, such as bottles and closures.

9.2.1 Plastic film and sheet for packaging

As per the definition, the thickness of a film should be less than 100 µm (1 µm = 10^{-6} m). Film is used to cover product, to overwrap packaging (single packs, groups of packs, palletised loads), to make sachets, bags and pouches, and is combined with other plastics and other materials in laminates, which in turn are converted into packaging. Plastic sheets in thicknesses up to 200 µm are used to produce semi-rigid packaging such as pots, tubs and trays.

The characteristics of plastic films and sheets are dependent on the plastic(s) used and the method of film manufacture together with any coating or lamination. In film and sheet manufacture, there are two different methods of processing the molten plastic which is extruded from the extruder die. In the *cast* film process,the molten plastic is extruded through a straight slot die onto a cooled cylinder, known as the chill roll.

In the *blown*, or tubular, film process, the molten plastic is continuously extruded through a die in the form of a circular annulus, so that it emerges as a tube. The tube is prevented from collapsing by maintaining air pressure inside the tube or bubble.

In both the processes, the molten polymer is quickly cooled and solidified to produce a film which is reeled and slit to size.

For increased strength and improved barrier properties, film can be stretched to realign, or orient, the molecules in both the machine direction (MD), and across the web in the transverse (TD) or cross direction.

Film stretched in one direction only is described as being *mono-oriented*.When a film is stretched in both the directions, it is said to be *biaxially orientated*. Packing the molecules closer together improves the gas and water vapour barrier properties. Orientation of the molecules increases the mechanical strength of the film.

Oriented films are brought close to their melting point to anneal or release stresses in them and to minimize the amount of shrinkage which may occur when being heated in a post-production process such as printing or heat sealing. Failure to anneal heat set films will ensure that they have very unstable thermal characteristics and allow the films to shrink tightly onto cartons or bottles when heated.

It is difficult to puncture or start a tear in an oriented film, but once punctured, the alignment of the molecules allows easy increase of the rupture and tear. This feature is made use of to assist the opening of film sachets by incorporating a tear-initiating notch mechanically into the sealing area.

The majority of plastic films are transparent and not easily coloured by dyeing or adding pigments. In order to develop opacity, films can be cavitated during film manufacture. Cavitation causes internal light scattering, which provides a white or pearlescent appearance. With some plastics, such as cast PE, a chemical compound can be added to the plastic resin, which gives off a gas such as nitrogen or carbon dioxide, when heated in the film manufacturing process. The small gas bubbles in the plastic cause light scattering, which gives the film a pearlescent appearance.

However, because oriented films are thin, there is the probability of the bubbles being so large that the film may be ruptured. So instead of using gas bubbles, a shearing compound or powder is added to the polymer, causing internal rupturing of the plastic sheet as it is being stressed. This causes voids in the film and light is scattered across the whole spectrum. Incident white light is reflected inside the film as a result of the differing refractive index between the plastic and free air. The process reduces the density of the film and may result in more cost-effective packaging as a result of the increased area yield.

The technique of pigmenting plastics has been developed using white compounds such as calcium carbonate or, more usually, titanium dioxide, to give a white appearance. The addition of such inorganic filler, however, increases the density by up to 50%, lowering the yield and increasing the risk of mechanically weakening the film.

Metalizing with a very thin layer of aluminium is another way to achieve opacity by causing a high proportion of incident light to be reflected offthe surface away from the film. This technique has the additional benefit of improving barrier properties.

Transparency, the opposite of opacity, depends on the concerned polymer and on the way the film has been produced. If the film is allowed to cool down slowly, then large crystals may be formed and this gives the film a hazy appearance due to the diffraction and scattering of incident light by the crystals. Transparency improves as polymer crystallinity decreases and is also influenced by additives in the film. If the size of the additive particle is too large or if, as with slip agents, they migrate to the surface, the film becomes hazy.

The surface of a film needs to be as smooth as possible to enhance the surface for printing. A rough surface will give a dull appearance to the final printed effect, which is generally considered to be less attractive than a shiny, mirror smooth appearance. Furthermore, a rough surface may give packaging machine slippage problems, as it may be difficult to make the film slideover machine parts without creating static electricity in the film. It is overcome by incorporating food grade additives in the film. Films will also tend toblock and become adhered layer to layer in the reel. Waxes, for example carnaubawax, are added to minimize the blocking. The action of a slip additive, such assilica, depends on the particles of silica migrating to the surface of the filmwhere they act like ball bearings holding the surfaces apart.

For marketing purposes, it may be desirable to create a unique impact on theshelf at selling point, and hence films have been developed which are rough on one side and have a gloss surface on the other. This is done by casting thefilm against the rough surface of a sand-blasted chill roll.

It is possible to combine streams of molten plastic from separate extrudersin the die to make co-extrusions. Higher productivity is attained for a giventhickness of film if the same plastic is extruded in two or more layers andcombined in the die to form a single film. Co-extrusion is fast developing area, with extruders capable of combining up to seven layers of differingplastics to achieve specific properties and characteristics.

9.2.2 Pack types based on use of plastic films, laminates

Single films, co-extruded films and coated and laminated films in reel form areused to make plastic bags, sachets, pouches and overwraps.

Plastic bags are made by folding, cutting and sealing with welded seamswhich are also cut in the same operation. Pouches are generally made from laminates. They may be formed on the packing machine either from one reel byfolding, or from two reels and sealing, inside face to inside face on three sidesprior to filling and closing. The pouches travel horizontally on these machineswith the product filled vertically.

Free-flowing products such as granules and powders can also be filled vertically on form, fill, seal machines where the film is fed vertically from the reel. These packs are formed around a tube, through which the previouslyapportioned product passes. A longitudinal heat seal is made either as a finseal, with inside surface sealing to inside surface, or as an overlap seal, dependingon the sealing compatibility of the surfaces. The cross seal is combined withcutting to separate the individual packs.

Solid products such as chocolate bars are packed horizontally on form, fill, sealmachines. Biscuits can be packed in this way, provided they are collatedin a base (plastic) tray, though they are also packed at high speed on roll-wrappingmachines with the ends of the film gathered together and heat sealed.

Products packed in cartons are often overwrapped with plastic film, e.g.chocolate assortments and tea bags. The cartons are pushed into the network offilm, a longitudinal seal is made and the end seals are neatly folded, envelopestyle, prior to sealing with a hot platen which presses against the folded ends.

Shrink wrapping is similar to the overwrapping described above, except thatthe packs pass through the heated tunnel once the cross seal is made – there areno end seals. The film shrinks over the ends of the pack, the extent dependingon the width of the film used.

9.2.3 Rigid plastic packaging

Bottles are prepared by extrusion blow moulding. A thick tube of plastic is extrudedinto a bottle mould which closes around the tube, resulting in the characteristicjointed seal at the bottom of the container. Air pressure is then used toforce the plastic into the shape of the mould. After cooling, the mould isopened and the item removed. (The bottle shows a thin line in the positionwhere the two parts of the mould are joined.) Blow moulding is used for milkbottles (HDPE) and wide mouth jars.

It is possible to apply co-extrusion to extrusion blow moulding so that multi-layered plastic containers can be made with a sandwich of various plastics. Anexample would be where high oxygen barrier, but moisture sensitive, EVOH is sandwiched between layers of PP to protect the oxygen barrier from moisture.This construction will provide for a 12–18 month shelf life for oxygen-sensitiveproducts such as tomato ketchup, mayonnaise and sauces.

A variation of injection and extrusion blow moulding is to stretch the pre-form after softening it at the second stage and then stretching it in the direction of the long axis using a rod. The stretched pre-form is then blow moulded which results in biaxial orientation of the polymer molecules, thereby increasing strength, transparency, gloss and gas barrier. Injection stretch blow moulding is used to make PET bottles for carbonated beverages.

Screw cap and pressure fit closures with precise profiles are made by injection moulding. Wide mouth tubs and boxes are also made by injection moulding.

Not only are injection moulded items very accurate dimensionally but they can also be made with a very precise thickness. It should be noted that co-extrusion is not possible with injection moulding.

There are many food applications for rigid and semi-rigid thermoformed containers. Examples include a wide range of dairy products, yoghurts etc. in single portion pots, fresh sandwich packs, compartmented trays to segregate assortments of chocolate confectionery and trays for biscuits. Thermoforming can be combined with packing on in-line thermoform, fill and seal machines. These machines can incorporate aseptic filling and sealing.