13 Aseptic Packaging of Foods

13.1 INTRODUCTION

Aseptic packaging is the filling of sterile containers with a commercially sterile product under aseptic conditions, and then sealing the containers so that reinfection is prevented; that is, so that they are hermetically sealed. Figure 13.1 illustrates the key aspects of aseptic packaging in diagrammatic form. The term *aseptic* implies the absence or exclusion of any unwanted organisms from the product, package or other specific areas, while the term *hermetic* (strictly *air tight*) is used to indicate suitable mechanical properties to exclude the entrance of microorganisms into a package and gas or water vapor into (or from) the package. The term *commercially sterile* is generally taken to mean the absence of microorganisms capable of reproducing in the food under nonrefrigerated conditions of storage and distribution, thus implying that the absolute absence of all microorganisms need not be achieved.

Currently, there are two specific fields of application for aseptic packaging: (1) packaging of presterilized and sterile product and (2) packaging of a nonsterile product to avoid infection by microorganisms. Examples of the first application include milk and dairy products, puddings, desserts, fruit and vegetable juices, soups, sauces and products with particulates. Examples of the second application include fresh products such as fermented dairy products like yogurt.

The three major reasons for the use of aseptic packaging are (1) to take advantage of high temperature-short time (HTST) sterilization processes, which are thermally efficient and generally give rise to products of a superior quality compared to those processed at lower temperatures for longer times, (2) to enable containers to be used that are unsuitable for in-package sterilization and (3) to extend the shelf life of products at normal temperatures by packaging them aseptically.

13.1.1 Historical Development

The first aseptic packaging of food (specifically milk in metal cans) was carried out in Denmark by Nielsen prior to 1913, and a patent for this process (termed aseptic conservation) was granted in 1921. In 1917 in the United States, Dunkley patented a method of sterilizing cans and lids with saturated steam; the cans were then filled with a presterilized product. In 1923, aseptically packaged milk from South Africa reached a trade fair in London in perfect condition. The American Can Company developed a filling machine in 1933 called the heat-cool-fill (HCF) system, which used saturated steam under pressure to sterilize the cans and ends. The sterile cans were filled with sterile product and the ends sealed on in a closed chamber, which was kept pressurized with steam or a mixture of steam and air. Three commercial plants were built and operated on this principle until 1945.

In the 1940s in the United States, W.M. Martin developed a process in which empty metal cans were sterilized by treatment with superheated steam at 210°C, before being filled with cold, sterile product. In 1950, the Dole Company bought the first commercial aseptic filling plant on the market.

At the end of the 1940s, a dairy enterprise (Alpura AG, Bern) and a machinery manufacturer (Sulzer AG, Winterthur) in Switzerland combined their knowledge to develop ultra-high temperature (UHT)-sterilized, aseptically canned milk which was subsequently marketed in Switzerland in 1953. However, this system was not economical, mainly because of the cost of the cans, and Alpura, in collaboration with Tetra Pak of Sweden, went on to develop an aseptic system based on

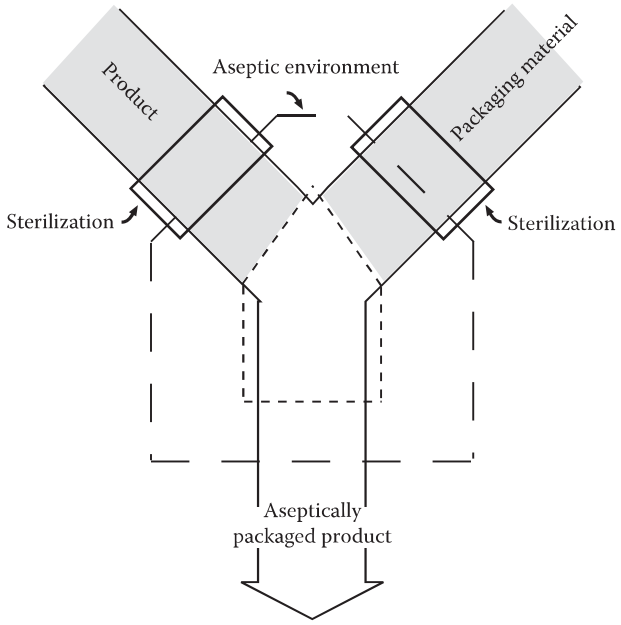

FIGURE 13.1 Diagrammatic representation of the aseptic packaging process.

paperboard cartons. The first milk with a long shelf life to be packaged in this manner was sold in Switzerland in October 1961 (Robertson, 2002).

13.1.2 Principles of Sterilization

The sterilization processes used in aseptic processing are variously described as HTST and ultra-heat treated or ultra-high temperature (UHT). The HTST process is defined as sterilization by heat for times ranging from a few seconds to 6 min. The International Dairy Federation has suggested that UHT milk should be defined as "milk which has been subjected to a continuous flow heating process at a high temperature for a short time and which afterward has been aseptically packaged. The heat treatment is to be at least 135°C for one or more seconds." More generally, the term UHT refers to in-line, continuous flow sterilization processes, which employ heat treatments within the temperature range 130°C–150°C with holding times of 2–8 s. The upper end of the temperature range tends to be used for low viscosity products such as milk, and the lower end for more viscous products.

The quality advantages that accrue from the use of HTST and UHT processes can best be understood by comparing the z value for microbial destruction with the z value for the loss of desirable quality factors in the food such as nutrients. A common z value for the former is 10°C, and for the latter, 33°C. A C_0 or cooking index has been proposed to describe the overall sensory quality deterioration which occurs during thermal processing. It is defined analogously to the F_0 value, except that the reference temperature is 100°C, rather than 121.1°C:

$$C_0 = 10^{(T-100)/z}T \tag{13.1}$$

The implications of the differences in z value are evident from a consideration of Figure 13.2. The regions which result in an F_0 value of 10 are typical of the low temperature-long time (LTLT) processes used for sterilizing foods in conventional canning processes; the C_0 values associated with such processes are in the order of 30–300. When an F_0 value of 10 is achieved at higher

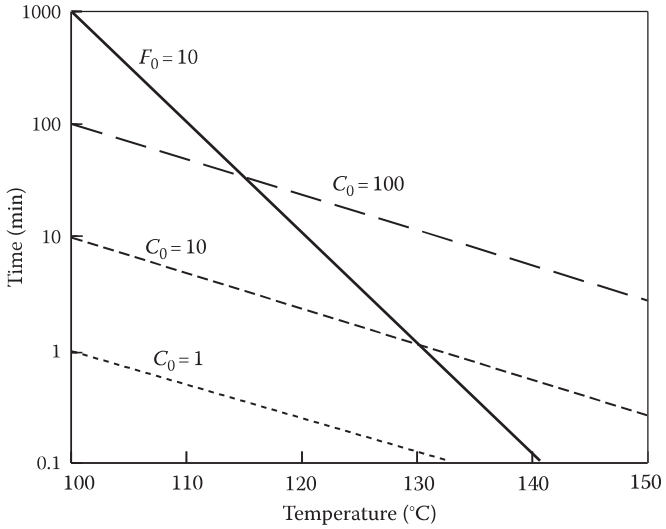

FIGURE 13.2 Comparative enzyme and bacterial spore inactivation curves.

temperatures (130°C–150°C), the corresponding C_0 values are around 1–10. Thus, while there is the same level of microbial destruction in both LTLT and HTST processes, the latter results in considerably less quality degradation and explains the preference of consumers for HTST- rather than LTLT-processed foods. Many chemical reactions such as nonenzymic browning, chlorophyll degradation and nutrient loss have z values of 33–50, and therefore the extent of the reaction at HTST conditions will be significantly less than at LTLT conditions.

One problem associated with the use of HTST processes is that of adequate enzyme inactivation. This is a particular problem with vegetable enzymes (especially peroxidases) and bacterial proteases and lipases produced by psychrotrophic bacteria, usually *Pseudomonas* spp. The heat resistance of bacterial enzymes is very high, and it has been calculated that one such enzyme is 4000 times more heat resistant than spores of *Geobacillus stearothermophilus*, the most resistant of the spores to be destroyed by a heat treatment process. Bacterial enzymes that have shown extreme heat resistance have z values in the range of 20°C–60°C. Thus, as the processing temperature is raised, an increasing percentage of the enzymes survive for the same sterilizing (F_0) performance. As a consequence, the probability of enzymic deterioration during storage of the processed product increases as the heat treatment temperature increases (Burton, 1988). This can lead to quality defects during storage of UHT milk products; for example, the proteases can led to the development of bitter flavors and age gelation (see Chapter 19 for more details).

From a commercial point of view, the aim of sterilizing food with the highest temperatures possible for the shortest possible times has lead to a number of different equipment designs and configurations. The heat exchange equipment can be classified into two groups:

1. Indirect heat exchange where the product and the heat exchange fluid are separated by the heating surface. There are three types:
   a. Tubular heat exchanger
   b. Plate heat exchanger
   c. Scraped surface heat exchanger
2. Direct heat exchange where steam is condensed in the product for heating, and vapor is removed from it by evaporation resulting in cooling. There are two means of heating:
   a. Steam injection (steam into product)
   b. Steam infusion (product into steam)

The objective in the design of the aforementioned equipment has been to improve the rate of heat transfer into and out of the food product in ways which minimize the required heating and cooling times. Generally, the direct systems give more rapid come-up and cooldown times than the indirect systems and present fewer problems with formation of scale and burn on. The indirect systems lend themselves to better heat recovery, tend to give a more stable output temperature and are not prone to contamination from condensables in the steam. In recent years, much work has been conducted on the use of microwave and dielectric heating, as well as resistive (ohmic) heating, for the sterilization of food. A few systems using such processes have become commercially available.

Regardless of the type of sterilizer used, the sterile product is cooled to an appropriate temperature, typically 20°C for low viscous food products like milk and fruit juices and 40°C for products of higher viscosity such as puddings and desserts. A presterilized container is then filled with the cooled, sterile product.

An aseptic filling system must meet a series of requirements, each of which must be satisfied individually before the whole system can be considered satisfactory. These are (Burton, 1988) as follows:

1. The container and method of closure must be suitable for aseptic filling and must not allow the passage of microorganisms into the sealed container during storage and distribution.
2. The container (or that part of it which comes into contact with the product) must be sterilized after it is formed and before being filled.
3. The container must be filled without contamination by microorganisms either from the equipment surfaces or from the atmosphere surrounding the filler.
4. If any closure is needed, it must be sterilized immediately before it is applied.
5. The closure must be applied and sealed in place while the container is still within a sterile zone to prevent the passage of contaminating microorganisms.

There are many possible ways of meeting the aforementioned requirements, and the remainder of this chapter will describe the major sterilization and packaging systems which have been developed and commercialized to meet the aforementioned requirements.

13.2 STERILIZATION OF PACKAGING MATERIAL FOOD CONTACT SURFACES

13.2.1 Required Count Reduction

The required count reduction (number of D values) for the sterilization of the food contact packaging material surface is determined by the type of product, its desired shelf life and likely storage temperature. For nonsterile acidic products of pH < 4.5, a minimum of four decimal reductions in bacterial spores is required. For sterile, neutral, low acid products of pH > 4.5, a six decimal reduction is required. However, if there is the possibility that *Clostridium botulinum* is able to grow in the product, then a full 12 decimal reduction process should be given.

The nonsterility rate or error rate, E_r, is the number of nonsterile or faulty packages as a proportion of the total number of packages processed over a given period. It can be calculated using the following equation:

$$E_r = A - N/R \tag{13.2}$$

where

N is the number of microorganisms on the food contact surface of the packaging material
A is the area of the food contact surface of the packaging material
R is the number of decimal reductions obtained in the sterilization process

Smaller containers with a smaller food contact surface area will have correspondingly less initial contamination and a less severe sterilization process will be needed to give a certain nonsterility rate E_r. Conversely, larger containers will require a more severe sterilization process. However, because container volume varies with the cube of the linear dimensions whereas surface area varies only with the square of the dimensions, the variation in the sterilization process according to container size is less than might be expected (Burton, 1988). Commercial requirements of less than one faulty package out of 10,000 produced are common (Moruzzi et al., 2000).

Because of the importance of the initial level of microbial contamination of the packaging material, steps should be taken to ensure that it is as low as possible. Thus, it should be produced, transported and stored under conditions which are as free from microorganisms as possible.

Three main sterilization processes for packaging material are in common use, either individually or in combination: irradiation, heat and chemical treatments. These will each be considered in turn.

13.2.2 Irradiation

13.2.2.1 Ionizing Radiation

Particle irradiation techniques using gamma rays from cobalt-60 or cesium-137 have been used to sterilize the interior of sealed but empty containers, especially those made of materials which cannot withstand the temperatures needed for thermal sterilization or that, because of their shape, could not be conveniently sterilized by other means. A radiation dose of 25 kGy or more is generally accepted to be sufficient to ensure sterility. The packages are sealed into microbial-proof containers prior to the irradiation treatment. It is also possible to use low-energy (80–150 keV), large area electron beams for the surface sterilization of packaging materials and containers including preforms, bottles and caps (Haji-Saeid et al., 2007).

13.2.2.2 Pulsed Light

By storing electrical energy in a capacitor and releasing it in short pulses, high peak power levels can be generated. The use of intense and short-duration pulses of broad-spectrum "white" light (200–1000 nm) to sterilize aseptic packaging material underwent considerable research and development in the 1990s. The duration of the pulses ranges from 1 µs to 0.1 s, and the flashes are typically applied at a rate of 1–20 flashes per second. Approximately 25% of the emitted light, which has an intensity of about 20,000 times that of sunlight at the Earth's surface, is UV, 45% visible and 30% infrared. Generally, a few flashes applied in a fraction of a second provide high levels of microbial inactivation. Despite a successful field trial, this system has not yet been commercialized. Surface topography has a complex influence on the efficacy of pulsed light treatments for surface microbial reduction (Oms-Oliu et al., 2010).

13.2.2.3 UV-C Radiation

UV radiation has a wavelength of 200–315 nm; it is most effective in terms of microbial destruction between 248 and 280 nm (the so-called *UV-C range*), with an optimum effectiveness at 253.7 nm. Mercury vapor lamps emit UV-C at 253.7 nm. UV-C irradiation is generally only used commercially in combination with hydrogen peroxide. Recently, UV (Excimer) lasers operating at 248 nm and using rare (noble) gas halides such as krypton fluoride have been commercialized. Illumination of the carton interior by laser light is problematic: the beam has to be projected physically to different areas of the carton interior by moving the carton into the laser beam (Warriner et al., 2004).

13.2.2.4 Plasma

Nonthermal plasma (NTP) is electrically energized matter and is composed of highly reactive species including gas molecules, charged particles in the form of positive ions, negative ions, free radicals, electrons and quanta of electromagnetic radiation (photons) at near-room temperature (Misra et al., 2011). NTP can be used for the surface decontamination of packaging materials, and a low-pressure

microwave plasma reactor has been evaluated for sterilization of PET bottles (Deilmann et al., 2008). A mixture of N_2, O_2 and H_2 gases is ignited inside a bottle; the resultant plasma consists of both UV photons and short-lived, antimicrobial free radicals. A treatment time of 5 s provided a reduction of 10^5 cfu. Commercialization of this cold sterilization process is presently under way.

13.2.3 Heat

Heat sterilization processes can involve either steam (moist heat) or dry heat. Steam is pure gaseous water with no air or other gases present. Dry heat is hot air in the absence of water molecules. The sterilization effect depends on time and temperature, and steam is much more efficient than dry heat. Steam sterilization at 121°C for 20 min is equivalent in effectiveness to dry heat sterilization at 170°C for 60 min (Robertson, 2011).

13.2.3.1 Saturated Steam

The most reliable sterilant is steam. However, in order to reach temperatures sufficiently high to achieve sterilization in a few seconds, the steam (and thus the packaging material with which it comes into contact) must be under pressure, necessitating the use of a pressure chamber. In addition, any air that enters the pressure chamber with the packaging material must be removed to prevent it interfering with the transfer of heat from the steam to the package surface. Finally, condensation of steam during heating of the packaging material surface produces condensate which, if not removed, could remain in the container and dilute the product.

Despite these problems, saturated steam under pressure is being used to sterilize plastic containers. For example, immediately after deep drawing, molded PS cups and foil lids are subjected to steam at 165°C and 600 kPa for 1.4 s (cups) and 1.8 s (lids). In order to limit the heating effect to the internal surface of the cups, the exterior of the cups is simultaneously cooled. This process has been shown to achieve a five to six decimal reduction in *Bacillus subtilis* spores.

13.2.3.2 Superheated Steam

Superheated steam was the method used in the 1950s for the sterilization of tinplate and aluminum cans and lids in the Martin–Dole aseptic canning process. The cans were passed continuously through 220°C–226°C saturated steam at normal pressure for 36–45 s, depending on the construction material given that aluminum cans have a shorter heating time because of their higher thermal conductivity.

13.2.3.3 Hot Air

Dry heat in the form of hot air has the advantage that high temperatures can be reached at atmospheric pressure, thus simplifying the mechanical design problems for a container sterilization system. Hot air at a temperature of 315°C has been used to sterilize paperboard laminate cartons where a surface temperature of 145°C for 180 s is reached. However, such a system is apparently only suitable for acidic products having a pH < 4.5.

13.2.3.4 Hot Air and Steam

A mixture of hot air and steam has been used to sterilize the inner surfaces of cups and lids made from PP, which is thermally stable up to 160°C. In this process, hot air is blown into the cups through a nozzle in such a way that the base and walls of the cup are uniformly heated.

13.2.3.5 Extrusion

During the extrusion of plastic granules prior to blow molding of plastic containers, temperatures of 180°C–230°C are reached for up to 3 min. However, because the temperature distribution inside the extruder is not uniform and the residence time of the plastic granules varies considerably, it is not possible to guarantee that all particles will achieve the minimum temperature and residence time

necessary to result in sterility. Extrusion results in a three to four decimal reduction in microbial spores, and therefore extruded containers should only be aseptically filled with acidic products with a pH < 4.5. For products with a pH > 4.5, it is recommended that extruded containers be poststerilized with hydrogen peroxide (H_2O_2) or peracetic acid (PAA).

13.2.4 Chemical Treatments

13.2.4.1 Hydrogen Peroxide

The lethal effect of H_2O_2 on microorganisms (including resistant spores) has been known for many years, with the first commercial aseptic filling system being devised in 1961. It used a combination of peroxide and heat to sterilize the surface of paperboard laminate packaging material. Although there have been many studies into the death of resistant spores in suspension in peroxide solutions, the actual mechanism of death is not fully understood. It has been found to induce higher heat resistance in *Bacillus sporothermodurans* strains, indicating that sublethal stress conditions may affect heat resistance (Scheldman et al., 2006). Because even concentrated peroxide solutions at room temperature have hardly any destructive effect, a minimum temperature of 70°C, a minimum concentration of 30% and a minimum time of 6 s are necessary to achieve destruction of the most resistant spores on packaging materials within seconds.

There are many uncertainties in the use of peroxide for surface sterilization, and therefore it is difficult to predict the sterilizing effect that any specific combination of peroxide concentration and temperature is likely to have. Therefore, in most situations where peroxide is used to sterilize packaging materials prior to aseptic filling, the sterilization conditions have been determined empirically. These conditions include the peroxide solution concentration, the quantity applied to the packaging material per unit area, the intensity of the radiant or irradiant heat (see the following) and the temperature and quantity of the drying air and the time for which it is applied.

The U.S. Food and Drug Administration has ruled that the concentration of H_2O_2 present in food products packaged in material sterilized by H_2O_2 must be no greater than 500 ppb (500 parts in 10^9) at the time of filling and must fall to approximately 1 ppb within 24 h. Since peroxide cannot be measured accurately in food products because of the presence of reducing compounds that rapidly eliminate it, checks of the initial level must be made on packs filled with water.

Because peroxide solution by itself is unable to sterilize packaging material, a number of systems have evolved which increase the efficacy of the peroxide treatment by combining it with heat and/or radiant or irradiant energy. These processes are briefly described in the following.

13.2.4.1.1 Dipping Process

In one process, the packaging material is unwound from a reel and passed through a bath of 30%–33% H_2O_2 solution containing a wetting agent to ensure uniform wetting of plastic surfaces that tend to be hydrophobic. The liquid H_2O_2 solution is reduced to a thin film, either mechanically by means of a squeeze roll, or with jets of sterile air; the adhering liquid film is then dried with hot air.

13.2.4.1.2 Spraying Process

In this process, H_2O_2 is sprayed through nozzles onto prefabricated packages. The peroxide is then dried using hot air. The death rate is dependent on the volume of sprayed H_2O_2 (larger volumes require longer drying times) and the temperature of the hot air. The trend now is to completely avoid spraying liquid droplets and instead use a mixture of hot air (130°C) and vaporized peroxide instead.

13.2.4.1.3 Rinsing Process

When the prefabricated container is of an intricate shape such that the spraying process is unsuitable, it can be rinsed with peroxide or a mixture of peroxide and PAA. After spraying, the container is drained and then dried with hot air. This process has been used to sterilize glass containers, metal cans and blow molded plastic bottles.

13.2.4.1.4 Combined with UV Irradiation and Heat

When UV irradiation and H_2O_2 are used together, they act synergistically, with the UV irradiation promoting the breakdown of the peroxide into hydroxyl radicals. The overall lethal effect is greater than the sum of the individual effects of peroxide and irradiation, the optimum effect being at a relatively low peroxide concentration of between 0.5% and 5%.

It is usual to use heat as well as UV irradiation and peroxide in the sterilization of packaging materials. The advantage of such a combination is that much lower concentrations of peroxide can be used (less than 5% compared with 30%–35% for peroxide and heat together) and the problems of atmospheric contamination by peroxide and residual peroxide in the filled product are reduced. However, because too high a peroxide concentration reduces the effectiveness of sterilization, strict control of concentration is essential.

13.2.4.2 Peracetic Acid

PAA (also known as peroxyacetic acid) is a liquid sterilant, which is particularly effective against spores. It is produced by the oxidation of acetic acid by H_2O_2, and the solution containing PAA and H_2O_2 is effective against resistant bacterial spores, even at 20°C (Cords et al., 2005). Unlike H_2O_2, PAA causes corrosion of metals such as iron, copper and aluminum. In closed containers, concentrations of PAA greater than 60% can lead to explosive decomposition and therefore it is normally stored at concentrations of 40% (Muranyi et al., 2010).

PAA is used for sterilizing filling machine surfaces as well as packaging materials such as PET bottles prior to aseptic filling, with the PET bottles being rinsed with sterile water rather than hot air.

13.2.5 Verification of Sterilization Processes

Sterilization of the packaging material is verified by inoculation of the surface of the web, cup or lid stock with the proper concentration of the test organism and allowing this to dry. The system is usually run as for a commercial test batch, and the finished containers are filled with an appropriate growth medium, incubated and observed for growth. At least 100 containers should be tested for each time, temperature or sterilizing agent concentration.

13.3 ASEPTIC PACKAGING SYSTEMS

The aseptic packaging system must be capable of filling the sterile product in an aseptic manner, and sealing the container hermetically so that sterility is maintained throughout the handling and distribution processes. An aseptic packaging system should be capable of meeting four criteria:

1. Able to be connected to the processing system in a manner that enables aseptic transfer of product to take place
2. Able to be effectively sterilized before use
3. Able to carry out the filling, sealing and critical transfer operations in a sterile environment
4. Able to be cleaned properly after use

The type of packaging material used is influenced by the nature of the product, the cost of both the product and the package and the preferences of the consumer. Although the most widespread consumer package for aseptic foods is the paperboard laminate carton, five major categories of aseptic packaging equipment are available and their major features and characteristics are described in the following.

13.3.1 Carton Systems

The carton material consists of layers of unbleached and/or bleached paperboard coated internally and externally with polyethylene, resulting in a carton that is impermeable to liquids and in which

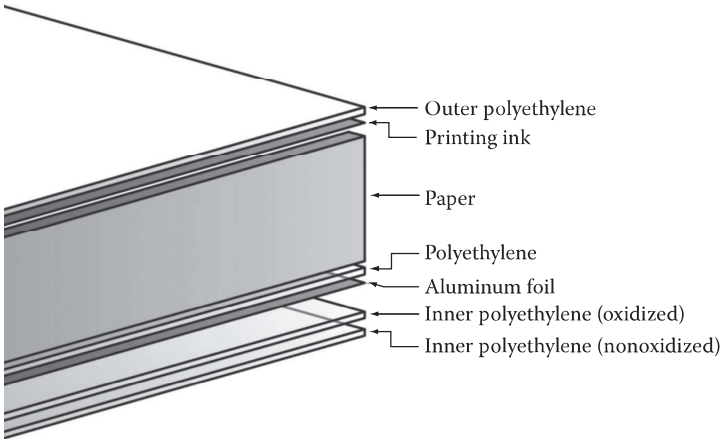

FIGURE 13.3 Typical structure of a paperboard laminate carton for aseptic filling.

the internal and external surfaces may be heat sealed. There is also a thin (6.3 μm) layer of aluminum foil which acts as an O_2 and light barrier. The structure of a typical paperboard carton is shown in Figure 13.3. The functions of the various layers are as follows:

1. The outer polyethylene (12 gsm) protects the ink layer and enables the package flaps to be sealed.
2. The bleached paperboard (186 gsm) serves as a carrier of the decor and gives the package the required mechanical rigidity.
3. The lamination layer of polyethylene (20 gsm) binds the aluminum to the paperboard.
4. The 6.3 μm thick aluminum foil (17 gsm) acts as a gas barrier and provides protection of the product from light.
5. The adhesive layer of poly(ethylene-*co*-methacrylic acid) (6 gsm) ensures good adhesion between the aluminum foil and the polyethylene.
6. The inner polyethylene layer (29 gsm) provides a heat sealable liquid barrier.

13.3.1.1 Form-Fill-Seal Cartons

The packaging material is supplied in rolls that have been printed and creased, the latter being necessary to ease the forming process. A longitudinal seal strip (LS-strip) is sealed to one edge (the reason for this is described later). The LS-strip is composed of a core layer of either PET or EVOH depending on the O_2 sensitivity of the product, coated with LDPE or LLDPE or a mixture of the two. The packaging material is sterilized using one of two procedures: a wetting system or a deep bath system.

In the wetting system, a thin H_2O_2 film (15%–35% concentration), containing a wetting agent (Tween-20 or polyoxyethylene sorbitan monolaurate at 0.2%–0.3%) to improve the formation of a liquid film, is applied on the inner packaging material surface. The material then passes through a pair of rollers to remove excess liquid and under a tubular electric heater, which heats the inside surface to about 120°C and evaporates the H_2O_2.

In the deep bath system, the packaging material is fed through a deep bath containing H_2O_2 (35% concentration) at a minimum temperature of 70°C, the residence time being 6 s. After squeezer rollers have removed much of the peroxide, both sides of the material are heated with air (directed through nozzles) at a temperature of 125°C to evaporate the peroxide.

The sterilized packaging material is fed into a machine where it is formed into a tube and closed at the longitudinal seal by induction heating. In the process, the LS-strip that was added prior to sterilization is heat sealed across the inner surface of the longitudinal seal to prevent contact between

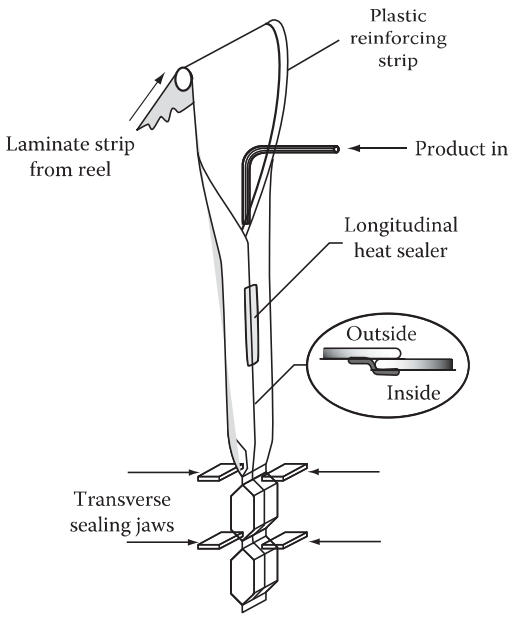

FIGURE 13.4 One method of forming cartons from a continuous web; the cross section of the longitudinal seal is enlarged to show the plastic strip which protects the internal edge of the carton.

the outside and the inside of the carton. It also provides protection of the aluminum and paperboard layers from the product, which could corrode or swell the layers if such a strip were absent.

The tube is then filled with the product and a transverse induction seal made below the level of the product, thus ensuring that the package is completely filled. Alternatively, the packages may be produced with a headspace of up to 30% of the total filling volume by injection of either sterile air or inert gases such as N_2. The sterilization, filling and sealing processes are all performed inside a chamber maintained at an over-pressure of 0.5 atm with sterile air.

One method of forming cartons from a continuous web is shown in Figure 13.4; also included in the diagram is a cross section of the longitudinal seal. The sealed packages are then pressed by molds into rectangular blocks, after which the top and bottom flaps or wings are folded down and heat sealed to the body of the package using electrically heated air.

13.3.1.2 Prefabricated Cartons

In systems of this type, prefabricated carton blanks are used, the cartons being die cut, creased and the longitudinal seam completed at the factory of origin by skiving the inner layer of board and folding it back (see Figure 13.5). The cartons are delivered to the processor in lay-flat form ready to be finally shaped in the filler and the top seam formed and sealed. Although the aforementioned operations take place under nonsterile conditions, steps are taken to avoid recontamination.

The aseptic area of the filling machine consists of several separate functional zones where operations are carried out in sequence. Sterility is maintained in each zone by a slight overpressure of sterile air. The inside surface of the carton is sterilized with a 35% solution of H_2O_2, delivered either as a fine spray or a vapor in hot air that condenses as liquid peroxide on the carton surface. The peroxide is removed by a jet of hot air at 170°C–200°C. Alternatively, the inside of the carton can be sprayed uniformly with a 1%–2% solution of H_2O_2 and then irradiated for about 10 s with high intensity UV radiation. The peroxide is then heated and removed by hot air jets. The problems of residual peroxide in the carton and peroxide contamination in the surrounding atmosphere are more easily dealt with in this latter process because the total quantity of peroxide used is 20–30 times less than in the former.

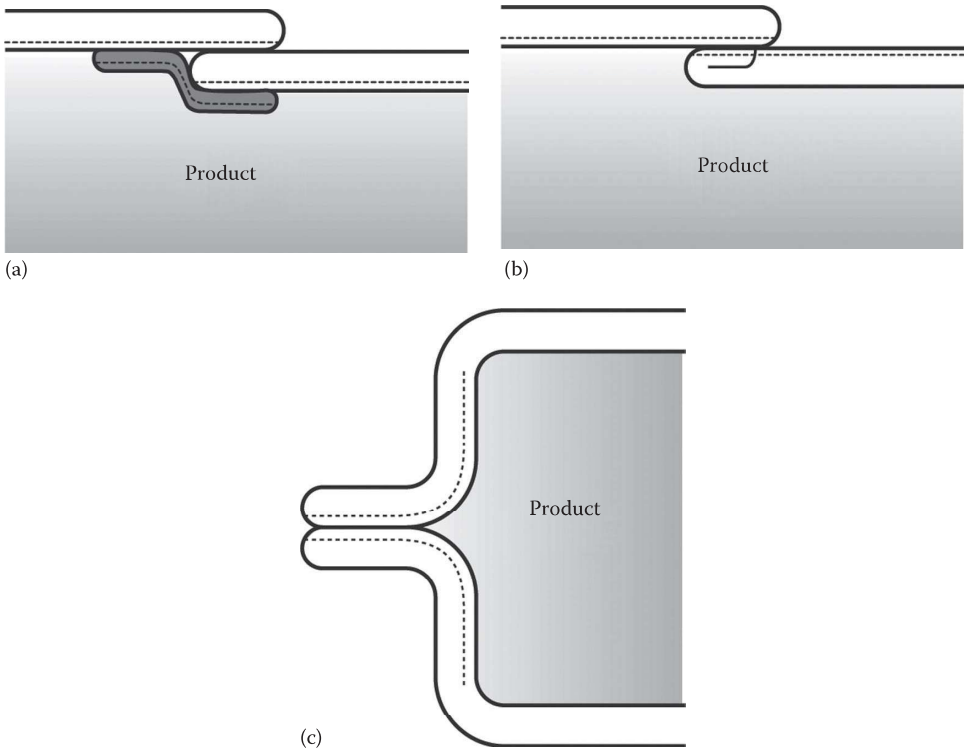

FIGURE 13.5 Three types of side seams used with aseptic paperboard laminate cartons. (a) plastic strip overlaps internal side of longitudinal seam (as used with form-fill-seal cartons); (b) inner layer of board is skived (pared down) and the reduced-caliper edge is folded back and sealed off from the product (as used with prefabricated cartons) and (c) fin seal which avoids exposure of the product to any cut edges of paperboard.

The next stage of the process is filling. A certain amount of headspace is always advisable to ensure that the package can be opened and poured without spilling. A headspace is essential when the contents require shaking (as is the case with flavored milk drinks and pulpy fruit juices). It is advantageous to fill the area between the product and the top of the package with steam or an inert gas such as N_2 for products such as fruit juices. If steam is used, then the headspace volume is reduced as a result of condensation of the steam. A headspace is also crucial when it is not possible to seal the filled package through the product such as when it contains particulate solids. A headspace ensures that sealing can occur above the product line, thus preventing solid material from getting caught up in the top seal where its presence would lead to loss of sterility.

The carton top is folded and closed after filling, and the seal made by either induction heating or ultrasonic welding. Production and date codes are added afterward by ink jet printing or by burning into the top seal. The protruding flaps or "ears" on each side are folded down and sealed to the package with hot air. The finished cartons are then discharged onto a conveyor belt, ready for the final packing process.

13.3.2 Can Systems

This system was pioneered by W.M. Martin in the late 1940s, and, in 1950, the first commercial aseptic filling machine was commissioned by the James Dole Corporation in California for soups. The system uses superheated steam at temperatures of up to 225°C for up to 40 s to sterilize the cans and can ends. The three basic types of metal cans (tinplate, ECCS and aluminum) can be used in this system and various can sizes from 125 mL to 22 L can be handled. Product quality is the same

for large and small containers, an important feature with products which are difficult to process because of heat sensitivity or poor heat transfer properties.

After the cans are filled with the cold, sterile product, they are sealed using a conventional can seamer which has been modified for aseptic operation. Superheated steam is used to maintain asepsis during the filling operation and results in a high vacuum in the can. To prevent excessive vacuum in the can which could later lead to leaker spoilage, either sterile air or N_2 is blown into the headspace of the can immediately prior to seaming; this results in a vacuum of about 27 cm Hg compared with 50–60 cm Hg without air injection.

An additional important packaging-related factor concerns the lining compound in the lid. At the seaming temperature of 220°C, it is very plastic, and for this reason the seamed can must be transported in an upright position for at least 15 s to allow the compound to settle down and hermetically seal the can. Only then may the can be rinsed to remove filling residues or transported by rolling.

Composite cans consisting of a spirally wound body made from laminations of foil, plastics and paper with metal ends are sterilized using hot air at 143°C for 3 min. This process renders the container and end sterile in respect of acid-tolerant microorganisms such as yeasts, molds and non-spore-forming bacteria, thus permitting the aseptic packaging of acidic products such as fruit juices and other beverages. The use of steam to sterilize composite cans is not practicable since swelling of the paper layers would result.

13.3.3 Bottle Systems

13.3.3.1 Glass

Aseptic filling into glass bottles was attempted following on from the success of aseptic filling into metal cans. The bottles were sterilized either by saturated steam under pressure or by dry heat. When the latter process was used, extended cooling with sterile air was required to minimize the risk of bottle breakage from thermal shock when bottles were filled with cool product. None of the prototypes for aseptically filling glass bottles were successfully commercialized.

However, there has been a revival of interest in aseptic packaging in glass containers and several new systems have been developed. One of these uses dry heat sterilization, while others use a H_2O_2 bath or spray followed by drying with hot air. None of these new glass bottle systems has found widespread acceptance.

13.3.3.2 Plastics

Blow molded plastic bottles have been used for many years as a cheaper alternative to glass for nonreturnable containers. HDPE and PP are the two most common thermoplastics used, sometimes with pigments added so that the contents are better protected from light. It is also possible to mold bottles from multilayered material, resulting in much improved barrier properties and thus longer shelf lives for the products packaged in them. More recently, aseptic PET systems capable of packaging a variety of products including milk, juice and water have been commercialized.

Four different types of systems are in use, as described below.

13.3.3.2.1 Nonsterile Bottles

After blowing (either immediately prior to the following steps or on a separate site), the plastic bottles are conveyed into a sterile chamber, the air pressure of which is kept at a slight overpressure with sterile air. The bottles are inverted and sprayed inside and outside with a solution of H_2O_2 or PAA. The H_2O_2 is evaporated by passing the bottles through a hot air tunnel prior to filling. Bottles sterilized with PAA are rinsed with sterile water and then filled. A chemically sterilized, heat sealable closure such as a plastic film or cap is then applied.

13.3.3.2.2 Sterile Blown Bottles

Bottles are extruded, blown with sterile air and sealed under conditions that ensure internal sterility. The sealed bottles are then introduced into a sterile chamber (maintained under a slight positive pressure) where the outside surfaces are sterilized with H_2O_2 sprays. The closed top of the bottle is cut away, the neck trimmed, the bottle filled and a foil cap or heat sealable closure (which has been sterilized outside the chamber) is applied.

13.3.3.2.3 Sterilization of Preformed Containers

Recently, a dry decontamination system that uses 5–15 mg of H_2O_2 per preform (40 times less than those involving bottle rinsing) was commercialized; no water is needed for the process. The method works by first transferring preforms by the neck on a wheel from the in-feed to the oven entrance. Nozzles, calibrated to between 120°C and 140°C, apply the H_2O_2 vapor, which condenses evenly on the internal walls of the performs; these are then heated in the oven to 100°C.

13.3.3.2.4 Single Station Blowing, Filling and Sealing

In this mechanically complex system, the separate operations of parison extrusion, blow molding, bottle filling and sealing all take place in sequence in a single mold. Sterility of the inside surface of the containers is ensured by the high temperature of the plastics material during extrusion of the parison, and the use of sterile air for blowing. The thermoplastics used for this type of container include HDPE, PP and PETG copolyester, the extrusion temperature ranging from 165°C to 235°C depending on the resin. After filling, the tube projecting from the bottle mold is vacuum formed or sealed with jaws into a cap which closes the bottle. No special arrangements to ensure sterility are required because the filling and sealing are carried out within the closed mold.

13.3.4 Sachet and Pouch Systems

13.3.4.1 Form-Fill-Seal Systems

In this system, a vertical form-fill-seal machine operates in a sterile chamber. The packaging material is passed through 35% H_2O_2 and then drained, dried with hot air and irradiated with UV light. The film used is typically a laminate of LLDPE with a center layer of EVOH copolymer and carbon black to give the pouch the required shelf life. Pouches typically have fin seals on all four sides.

An aseptic pouch, similar in structure to the laminate carton shown in Figure 13.3, was commercialized in 1997, the difference being that the paperboard was replaced by paper of 80 gsm. Similar filling machines and procedures are used as for aseptic cartons.

Recently, a chalk-filled multilayer plastic pouch material was commercialized. It consists (from outside in) of a PP layer, a 40% w/w calcium carbonate-filled PP layer to provide stiffness and integrity, EVOH to protect against O_2, a carbon black layer to protect against light and LLDPE as a sealing and food contact layer (Figure 13.6). The material is presterilized using electron beams. Compared to other traditional aseptic packaging concepts, this system is claimed to offer lower environmental impacts in terms of energy consumption, waste generation and emissions to air and water.

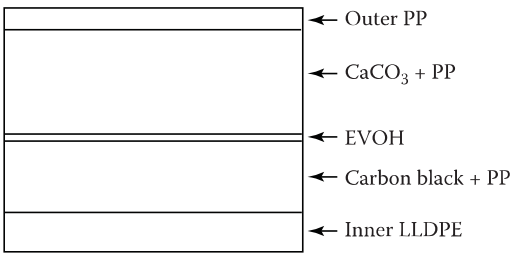

FIGURE 13.6 Structure of chalk-filled plastic material for aseptic pouch.

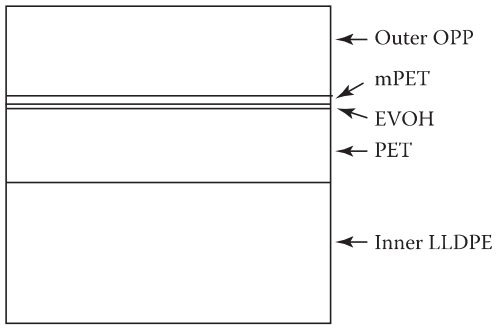

FIGURE 13.7 Structure of bag used for aseptic bag-in-box system for packaging UHT products.

13.3.4.2 Bag-in-Box System

An aseptic bag-in-box system for packaging UHT products consists of a filler that provides a sterile, enclosed product transfer path from process to package utilizing a unique steam-sterilized double-membrane technology. The inner membrane, heat sealed under completely secure conditions during the fill process, remains sealed until the pack is opened by the consumer, thus eliminating any risk of product contamination during storage and transport. Bags range in size from 1.5 to 1400 L and contain EVOH and metalized PET (mPET) as barrier layers (Figure 13.7). Bags are manufactured fully sealed with minimum air content and then sterilized using gamma radiation. During filling, the transfer area is fully sterilized before the first membrane is pierced to ensure a completely aseptic transfer of product. Sterilization is accomplished using only steam, eliminating the need for chemical sterilants, and the steam inlet is specially designed to safeguard the quality of the product. The double membrane on the bags also ensures complete tamper evidence both before and after filling. After filling, the bag is placed inside a paperboard box.

13.3.4.3 Lay-Flat Tubing

This system uses a blown film polymer in the form of lay-flat tubing so that only a transverse seal is required to form the bag. The assumption is made that the inside of the tubing is sterile because of the temperature achieved during the extrusion process. Either a single film or a coextrusion material can be used. The tubing is fed from the reel into a sterile chamber in which an overpressure of air is maintained. The sachets are sealed at the bottom, cut and moved to a filling section. They are sealed at the top after filling and leave the chamber through a water seal.

13.3.5 Cup Systems

13.3.5.1 Preformed Plastic Cups

The cups are usually made from HIPS, PP or coextruded, multilayered polymers if improved barrier properties are required. A typical example of the latter would be an outer layer of HIPS, a laminating adhesive, a barrier layer of PVdC or EVOH copolymer, a laminating adhesive and finally LDPE.

The cups are fed onto a conveyor which is inside a sterile tunnel supplied with sterile air. The cups are sprayed inside with 35% H_2O_2 solution, and after about 3 s, the solution is removed with compressed hot air at a maximum temperature of 400°C, depending on the material from which the cups are made. The inside surface of the cups reaches a temperature of about 70°C which completes surface sterilization and reduces the peroxide residue to acceptable levels.

Cups can also be sterilized by carrying them through a 35% H_2O_2 bath at 85°C–90°C before heating and passing through a water bath. The cups then enter a sterile chamber where sterilization is completed by spraying with sterile water and drying with hot air.

The lidding material (usually aluminum foil with a thin coating of a thermoplastic polymer) is typically sterilized with 35% H_2O_2 which is then removed either by radiant heat, hot sterile air or

by passing the material over a heated roller. In some systems, UV radiation is used, either alone or in conjunction with peroxide.

13.3.5.2 Form-Fill-Seal Cups

The plastic material (commonly HIPS because it is easily thermoformed) in the form of a web is fed from a roll into a thermoformer to give multiple containers (still in web form). More complex coextruded multilayer materials that incorporate a barrier layer of either PVdC or EVOH copolymer can also be treated in this way. However, mechanical forming (rather than thermoforming) is used if an aluminum foil layer is incorporated into the laminate.

The advantages in thermoforming cups from a reel compared to using premade cups include a favorable price ratio, simplified handling because the constant reloading of magazines is avoided, higher output by utilizing multiple tools, smaller storage requirements for the packaging materials and maximum sterility of the cups (both inside and outside surfaces) and lids from running flat material through sterilizing baths.

Sterilization of the web is carried out prior to forming by passing it through a 35% H_2O_2 bath at room temperature, with typical residence times being in the order of 15 s. Air knives remove surplus liquid prior to the web passing through a sterile tunnel where it is prepared for thermoforming by heating it to 130°C–150°C. Alternatively, radiant heat can be used to heat the web after it has left the peroxide bath. The containers are then formed (usually by a combination of mechanical forming and compressed air) into a water-cooled mold below the web. Sterilization of the lidding material is achieved in a similar manner to the container web.

An alternative type of form-fill-seal system sterilizes the containers after they have been formed using saturated steam under pressure at 3–6 atm (135°C–165°C) for about 1.5 s; the lidding material is again sterilized in a similar manner.

Using the high temperatures reached during the extrusion process to ensure sterility is the feature of another form-fill-seal system based on coextruded multilayer films which typically contain PVdC or EVOH copolymer as a barrier layer. The outer layer of the coextrusion is peeled away within a sterile chamber, exposing a sterile inner surface which is then heated by radiation and thermoformed into the desired container shape. It is important that uniform wall thickness is maintained during the thermoforming process, otherwise the thickness of the barrier layer will vary and dramatically affect the shelf life of the product. The lidding material also has a peelable outer layer which is removed to expose a sterile material which can be heat sealed in place.

A special feature of the system is the in-mold labeling process, wherein the label is positioned in the mold and applied and heat sealed to the external surface of the container during the thermoforming process; this imparts strength to the container as well as providing an economical labeling system.

13.4 INTEGRITY TESTING OF ASEPTIC PACKAGES

Assessment of package integrity is one of the most critical issues in the aseptic packaging of foods, and it is imperative that package integrity be maintained to ensure the safety and quality of the product. In addition to the performance tests described in the following, the effects that shipping containers, palletizing, packaging materials and the form of packaging have on the integrity of the aseptic package are also important and should be evaluated before a particular aseptic packaging system is operated commercially.

Several performance tests are in use to assess the likelihood of an aseptic package maintaining its integrity during distribution and handling. Package and seal integrity have traditionally been verified using destructive methods such as biotesting, electrolytic testing, dye penetration or bubble testing. However, destructive test methods are often laborious and time consuming to perform, and clearly it is not possible to test and reject all defective packages.

There is growing interest in nondestructive (or noninvasive) package integrity testing, which allows the online testing of every package produced, while leaving both product and package intact.

Such tests need to meet three criteria: nonspecificity, high sensitivity and rapidity. Most nondestructive leak inspection systems are based on a stimulus–response technique with stimuli including pressure, a trace gas such as CO_2 or helium, and ultrasound. The package response can be package movement, pressure change, trace gas detection or sound attenuation. Recently, a cyclic voltametric method was developed to identify pinholes arising from cracks in the inner plastic layers of aseptic cartons (Hsu and Chang, 2007). An online pressure differential leak detector has also been shown to be effective in assessing the quality of seals in cartons in less than 30 s (Sivaramakrishna et al., 2007).

Other nondestructive tests involving computer-aided video inspection or automatic profiling of the packages have been developed and are being improved upon all the time. Profile scanning with aseptic packages is ineffective because, even if the package leaks and air enters, the package profile does not change immediately.

Despite considerable research in recent years, the availability of commercially viable, nondestructive package integrity testing equipment is still very limited. Continuing research is in progress and new possibilities may be commercialized in the coming years.

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