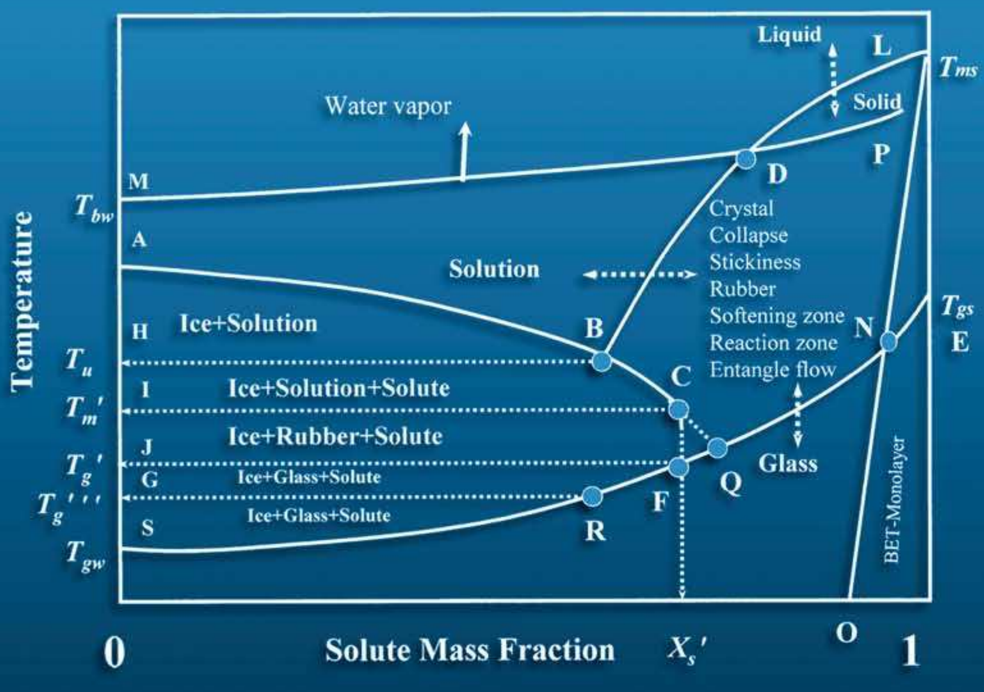
Handbook of Food Preservation

Second Edition



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CRC Press
Taylor & Francis Group

24

Canning and Sterilization of Foods

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24.1 Introduction

Sterilization is the complete destruction or elimination of all viable organisms in/on a food product being sterilized. Sterilization destroys yeasts, molds, vegetative bacteria, and spore formers, and allows the food processor to store and distribute the products at ambient temperatures, with extended shelf life. Sterilization procedures involve the use of heat, radiation, or chemicals, or physical removal of cells. The sterilization process consists of four distinct stages. First, the product must be heated to a temperature of 110°C–125°C to ensure sterilization. Second, the product requires a few minutes to equilibrate, since the surface will be hotter than the central portion of the container causing a temperature gradient. The equilibration stage allows reduction in the temperature gradient. Third, the product must be held at this temperature for a certain period to ensure a predetermined sterilization value designated by F_o value. Finally, the product has to be cooled mainly to arrest further heat treatment and avoid over cooking [1]. The basic principles of sterilization technology as applied to food processing are [2]:

- The processed product must be free from microorganisms capable of producing food-poisoning toxins and those microorganisms that cause food spoilage during product shelf life, until it is consumed.
- *Clostridium botulinum* spores are capable of growing in low-acid (pH $>$ 4.6) products during storage and hence must be heat treated to the equivalent of at least 121.1°C for 3 min (an F_o value of 3) to achieve a 12-decimal reduction of the microorganism.
- The processing conditions should be applied to the slowest-heating point referred to as "cold point." This facilitates the assumption that, when the slowest heating part is sterilized, by exposing it to the required time–temperature profile, the rest of the product will be sterilized.

Practically, complete sterilization will lead to deterioration in product quality and nutrients [3]. Hence, in practice, commercial sterility is targeted. Commercial sterility is defined as a product that has been optimally processed so that under normal conditions, the product will neither spoil nor endanger the health of the consumer and also retain the organoleptic properties and nutrients [4]. The pH of the product is an important factor in determining the severity of the sterilization process.

24.2 Theory of Sterilization

Thermal treatment of food products to render them free of pathogenic microorganisms is being practiced for several years. However, a method to quantify the microbial destruction that takes place during a thermal treatment has only been understood for the last 75 years. To determine the amount of microbial destruction that a thermal treatment delivers to a process requires both an understanding of the amount of heat delivered to every portion of the food product and the destruction kinetics of the microorganisms of interest. The amount of heat delivered by the sterilization process is dependent on the way in which the product is heated and on its physical nature. Process-dependent factors include processing equipment design, type of heating media, container, or food size and shape, product composition and viscosity (conduction or convection heated). The thermal destruction kinetics of microorganisms or their ability to be killed within the food matrix is dependent on a number of factors. These factors include pH of the product, levels and types of preservatives, water activity, the previous growth conditions of the microorganisms of concern, product composition, and competitive microorganisms [5].

The two types of bacteria of concern in food preservation are organisms of public health significance and spoilage-causing bacteria. In low-acid foods with a pH greater than 4.6, the organism of public health significance is *Clostridium botulinum*. Canned foods are processed based on the survival probability for *C. botulinum* of 10^{-12} or one survivor in 10^{12} cans. The organism most frequently used to characterize low-acid food spoilage by mesophilic spore formers is PA 3679, a strain of *C. sporogenes*. Most food companies accept thermal inactivation of 10^{-5} for mesophilic spore formers and 10^{-2} for thermophilic spore formers. The processing time depends on the bioburden of the most resistant bacteria in a particular food, the spoilage risk involved, and whether food can support the growth of potential contaminating bacteria [6]. Though a lot of research work has been carried out on the influence of different factors on the processing time and the corresponding sterilization value, a number of uncertainties still exist on the application of these factors to scientifically arrive at the exact processing conditions. These uncertainties have been discussed in detail [7]. To avoid any risk due to these uncertainties, a safety factor is added to increase the processing time to completely sterilize the food product, which invariably reduces the nutrient content and the increase in energy cost.

24.3 Methods of Sterilization

The food sterilization methods are divided into two categories: sterilization by heating (thermal processing) and sterilization without heating (nonthermal processing). Thermal processing is widely practiced in spite of some problems such as that the process of heating might reduce nutrition or deteriorate the quality of foods and that it is ineffective against certain types of bacteria. Thermal processing is further divided into two categories as in-container sterilization (bulk canning) and aseptic sterilization (processing). The principles involved in thermal sterilization of foods remain the same for both the methods.

24.4 Bulk Canning

24.4.1 Introduction

The thermal processing operation requires the heating of food products. For a low-acid food product (pH $>$ 4.6), the product is heated to temperatures above 100°C usually in the range of 115°C–130°C for a time sufficient to achieve a 12-log reduction of the spores of *C. botulinum* as defined in the Department of Health Code of Practice No. 10. Current practices are, however, to move to even higher temperatures and consequently a shorter process time to maximize the organoleptic and nutrient retention within the product. The time–temperature procedure required to render a product commercially sterile must be carefully determined using established procedures. Canned foods might be described as full-moisture, ambient-temperature stable food products regardless of the package form employed.

24.4.2 Processing Equipment

The food processing industry produces a wide range of products in a variety of containers. This requires the need of an equally wide range of processing techniques, retort designs, and operating procedures. Retorting systems can be subdivided in several ways.

24.4.2.1 Methods of Processing the Containers

The two types of retorts are batch retorts and continuous retorts. In batch systems, the retort is filled with product, closed, and then put through a processing cycle. In continuous retorting systems, containers are continuously fed into and out of the retort. Batch retorts are available in a number of configurations for various applications, including static, rotary, steam heated, and water heated with or without air overpressure. The air overpressure is necessary to maintain the integrity of the containers during retort operating cycles for glass and flexible containers.

24.4.2.2 Methods of Heating Medium

The heating medium used in retort are: steam, steam/air, water, direct flame or fluidized bed.

24.4.2.2.1 Saturated Steam

Latent heat is transferred to food when saturated steam condenses on the outside of the container. If air is trapped inside the retort, it forms an insulating boundary film around the cans, which prevents the steam from condensing and causes underprocessing of the food. It also produces a lower temperature than that obtained with saturated steam. It is therefore important that all air is removed from the retort by the incoming steam using a procedure known as venting [8]. After sterilization, the containers are cooled with water. Steam is rapidly condensed in the retort, but the food cools more slowly and the pressure in the containers remains high. An overpressure of air is therefore used to prevent strain on the container seams (pressure cooling). When the food has cooled to below 100°C, the overpressure of air is removed and cooling continues to approximately 40°C. At this temperature, moisture on the container dries to prevent surface corrosion, and label adhesives set more rapidly. Rigid polymer trays heat more rapidly than conventional container owing to their thinner cross section. Trays are processed in a conventional equipment using saturated steam at 121°C.

24.4.2.2.2 Hot Water

Foods are processed in glass containers or flexible pouches under hot water with an overpressure of air. Glass containers are thicker than metal cans to provide adequate strength, and this, together with lower thermal conductivity of glass, results in slower heat penetration and longer processing time than for cans and there is a higher risk of thermal shock to the container. Foods in flexible pouches heat more rapidly owing to the thin cross section of the container. This enables saving in energy and causes minimum overheating near the container wall. Liquid or semiliquid foods are often processed horizontally to ensure that the thickness of food is constant across the pouch. Vertical packs promote better circulation of hot water in the retort, but special frames are necessary to prevent the pouches from bulging at the bottom, which would alter the rate of heat penetration and hence the degree of sterilization achieved [8].

24.4.2.2.3 Flames

High rates of heat transfer are possible at flame temperatures of 1770°C. The consequent short processing times produce foods of high quality and reduce energy consumption by 20% compared with conventional canning. Each can is scanned by an infrared controller after processing, instead of the usual procedures. High internal pressures (275 kPa at 130°C) limit the application of this method to small cans [8].

24.4.3 Description of Processing Equipment

A variety of retorts, which use "pure" steam as the processing medium, i.e., steam free of air, are available. Steam retorts with batch container handling are vertical and horizontal still retorts, crateless retorts, and agitating retorts. Steam retorts with continuous containers handling include continuous rotary sterilizers and hydrostatic retorts. Retort operating procedures must ensure that uniform processing temperature is achieved and maintained throughout the location of containers during the process.

24.4.3.1 Batch/Still Retorts (Horizontal and Vertical)

Batch steam retorts are usually arranged either vertically (Figure 24.1) or horizontally (Figure 24.2) and are used for canned products that are placed into baskets immediately after seaming and are then placed inside the retort shell. The retort is made out of a metal shell pressure vessel that is fitted with inlets for steam (A), water (B), and air (E) and has outlet ports for venting (D) air during retort come up, and for draining (C) the retort at the end of the cycle. A pocket for thermometer or temperature recording probe/sensor and pressure gauge is located on the side of the vessel. To ensure adequate steam movement around the temperature sensors, the pocket is fitted with a constant steam bleed (D). On vertical retorts,

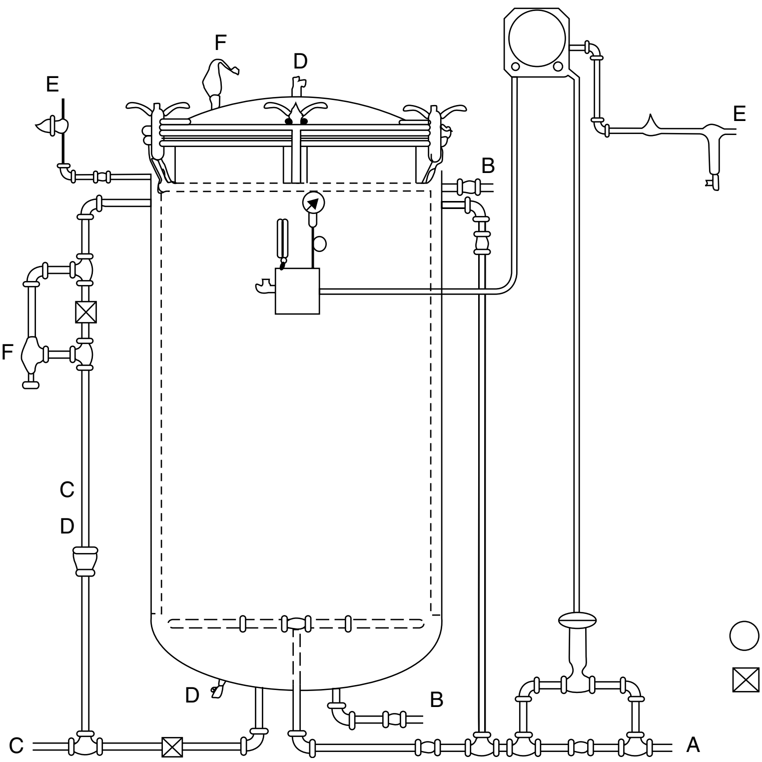

FIGURE 24.1 Vertical batch retort. (From Paine, F.A. and Paine, H.Y., eds., *A Handbook of Food Packaging*, 2nd edn., Chapman & Hall, New York, 1982, p. 224.)

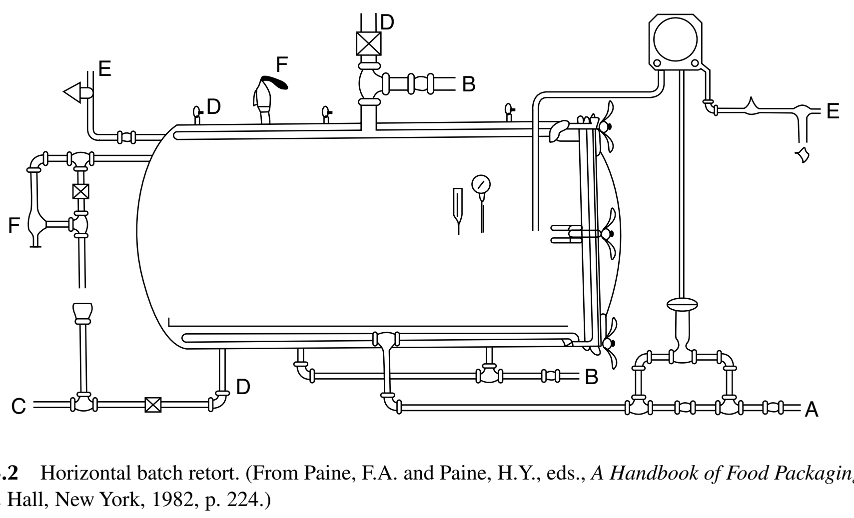

FIGURE 24.2 Horizontal batch retort. (From Paine, F.A. and Paine, H.Y., eds., *A Handbook of Food Packaging*, 2nd edn., Chapman & Hall, New York, 1982, p. 224.)

the lid is hinged at the top and secured to the shell during processing by several bolts. In horizontal steam retorts, the door is usually on the end of these machines, which can swing open. A safety valve and a pressure relief valve (F) are also provided for safety of the equipment [9].

The operating cycle for this type of retort involves loading the sealed containers into the retort, bringing the retort up to a temperature of around 100°C, and then allowing steam to pass through the vessel into the atmosphere for sufficient time so that all air in the retort and in between the cans is removed (venting) before the retort is finally brought up to the operating pressure and processing temperature. At the end of the processing time, the steam is turned off, and a mixture of cooling water and air is introduced into the retort to cool the cans. The purpose of the air is to maintain the pressure in the retort following the condensation of the residual steam after the initial introduction of cooling water. If this pressure is not maintained, the containers may deform due to the pressure imbalances between the internal pressure in the cans and the retort. As the temperature drops, the pressure in the retort may be controlled and gradually reduced until atmospheric pressure is reached and water can be allowed to flow through the retort, cooling the cans to a temperature of about 40°C before they are removed from the retort. Cans are removed from the retort at this temperature since this allows the surface of the cans to dry rapidly by evaporation thereby reducing the risk of leaker spoilage [10]. The water is preferably sprayed or alternatively the retort may simply be filled and allowed to stand for sufficient time for the cans to cool to 40°C before unloading the containers.

Both the systems are static in operation. For other types of product, it is possible to assist the rate of heat penetration by agitating the cans in the steam environment by rotation either about the horizontal axis in a horizontal retort or by rotation in the vertical plane in a vertical retort.

24.4.3.1.1 Steam/Air Retort Systems

The use of glass and plastic containers has increased the use of alternative retorting systems. With these types of containers, it is usually not sufficient to rely on the strength of the containers alone to counteract the build up of internal pressure during heating, but a constant overpressure of air is required to ensure the integrity of the package during heating. Thus, the heating medium used in this type of retort is often a mixture of steam and air in proportions designed to provide the necessary steam temperature and air overpressure to maintain the package integrity. To ensure adequate mixing of the steam and air, these retorts are fitted with a fan system to disperse the steam and air and eliminate the development of cold spots in the processing chamber [9].

Control of this type of retort system can be difficult, particularly in ensuring an adequately uniform temperature distribution in the retort environment when the steam is being mixed with cold compressed air. Here, unlike in the case of saturated steam retorts, the presence of air must not permit a reduction in the partial pressure of the steam and hence retort temperature, but only provide the overpressure needed to ensure package integrity. However, the steam and air must be intimately mixed so that pockets of cold steam/air mix do not form in the retort and lead to inadequate processing of the cans.

Three major classifications of steam/air retorts may be identified on the basis of methods used to mix and circulate the gaseous media: air makeup, positive flow, and forced convention. In steam/air processing, heat is supplied primarily from the latent heat of condensing steam, in contrast to sensible heat transfer in superheated water systems. As a result, it is essential to have a homogeneous steam/air mixture reaching all product locations. Since air is present during the process, it is unnecessary to purge all the air from the retort by venting prior to the holding period. However, a venting procedure is advantageous for initial heating of the retort shell, retort cars, and product support racks, as well as for providing faster heating to low-viscosity, convention-heating products.

24.4.3.1.2 Air Makeup Systems

These are designed such that after the desired temperature and pressure are reached, small valves along the top of the retort are left open to provide continuous venting of the retort during the heating period. The venting results in the pressure drop to less than the set point; this causes an air makeup valve to open to reestablish the retort pressure. As air enters the retort, the temperature tends to decrease; this signals for the addition of steam, which causes a further increase in pressure. Because of the repeated deviation from the temperature and pressure set point conditions, it may be difficult to maintain stable operating conditions using this methodology. Further, the addition of steam and air independently may produce a nonhomogeneous heating medium. In one system, activation of the air makeup valve also activated the steam valve such that steam and air, mixed outside the retort in the pipe connected to the spreader, flowed into the retort in response to a pressure drop; but this also could result in a pressure overshoot.

24.4.3.1.3 Positive-Flow Systems

These are designed to improve retort control and stability by controlling pressure and temperature independently. A temperature controller operates a proportional valve on the steam line, adding steam to the retort and maintaining the set temperature, while a pressure controller for the air inlet and vent lines maintains the retort pressure. Drop in the pressure to that below the set point causes the air supply valve vent to open and the vent valve to close. When the pressure exceeds the set point, the opposite occurs and the retort is vented. During processing, a constant flow of air is added to the retort, thereby causing the pressure to exceed the set point and the proportional flow vent valve to remain partially open during the process. Since steam and air are constantly vented under these conditions, temperature control would require the steam valve to remain partially open. Consequently, a continuous flow of steam and air would pass through the vessel to create a homogeneous mixture throughout the retort.

24.4.3.1.4 Forced Convection Systems

These, in contrast, utilize a powerful fan to circulate the heating medium through the retort and maintain a uniform mixture of steam and air throughout the vessel. During this process, steam is added to replace that which has condensed in heating the load, and, theoretically, after the process is established there should be no need to add air to the vessel until the cooling cycle begins [11].

24.4.3.2 Water Processing Retorts

This system is mainly used for the processing of glass jars. Raining water techniques (Figure 24.3) require the use of either an external steam injection system or heat exchanger system outside the direct environment of the retort. In the latter case, the cold water feeding the system is combined with the recycled heating medium and raised to the temperature required in the retort before being admitted to the sterilization chamber through a spray arrangement. The containers are arranged to allow good contact between the hot water heating medium and the product either using spacer bars or distribution plates. It is imperative that a good distribution of the water occurs, as otherwise stratification may occur and certain containers will receive inadequate heating process. Control of the temperature in this system is difficult, but the safest practice is to base the thermal process received by the product on the outlet temperature of the retort, i.e., the temperature measured in the return line to the heat exchanger [9]. The velocity of water in these retorts when passing over the packages is of vital importance, as this will influence the rate of heat transfer to the product due to its effect on the heat transfer coefficient. This is unlike the saturated steam retort processes where the heat transfer coefficient can be considered infinite [11].

24.4.3.3 Crateless Retort Systems

The vertical retort has grown in size, given up its crates, and become automated. These retorts are large and without crates and have been recognized as a universal symbol of low-acid food processing. They are usually 2.5 m high and 2 m in diameter with four to five times greater capacity than the conventional

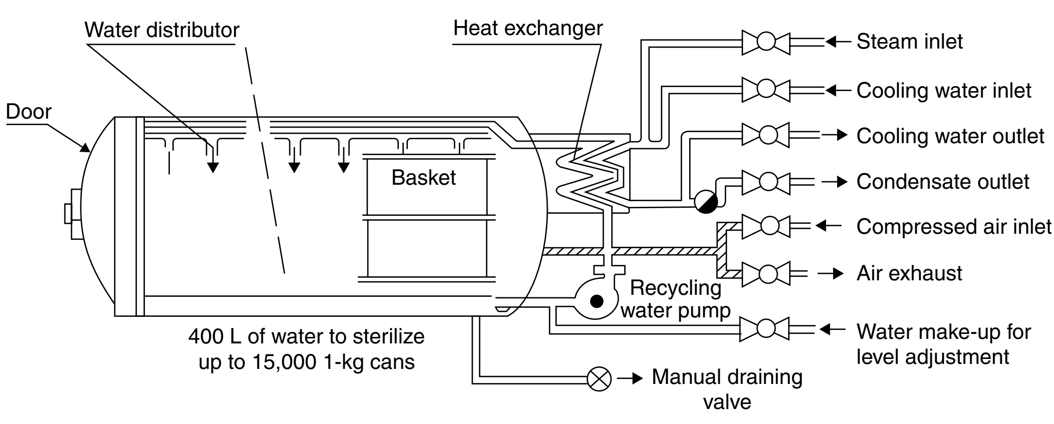

FIGURE 24.3 Water processing retorts. (From Richardson, R.S. and Selman, J.D., *Processing and Packaging of Heat Preserved Foods,* 1st edn., Rees, J.A.G. and Bettisson, J., eds., Chapman & Hall, 1990, p. 50.)

three-basket vertical retort. The crateless retort is filled with water, which acts as a cushion for cans filled from an automatic conveyor. After loading the cans a hydraulic lid is closed. Steam is admitted through the top opening and this forces the water out of the retort through the bottom opening. The hot water can be recycled in another retort or in the next cycle. After processing, cooling water is let in through the bottom and is discharged through overflow. After the cooling cycle, the retort is drained off and the bottom door is partially opened and the cans fall onto a shaker screen and are conveyed by a belt to the unscrambler [13,14]. It is critical that the steam condensate be removed from the bottom of the crateless retorts with top steam entry.

24.4.3.4 Agitating Retorts

There have been a number of different batch agitating retorts designed to provide product agitation by rotating the containers end over end or side over side. The one most used is the Orbital Rotary Pressure Stabilizer (FMC Corp., Madera, CAl.), also known as the Orbitort. The unique design of the orbital sterilizers allows for the simultaneous loading and unloading of containers by a reel and spiral assembly. This assembly consists of an inner reel with steps attached to a drum to hold the containers, and an outer reel, which holds a spiral. While the containers are being loaded, the outer reel (spiral) is locked to the shell, and the inner reel is rotated. This allows the containers to be indexed along the steps of the inner reel following the path of the spiral. After loading, the two reels are locked together, holding the containers in place. During the processing cycle, the locked reel assembly and containers are rotated at 15–35 revolutions per minute. Since the inner reel is constructed from a drum, the time required for venting of the orbital sterilizer is greatly reduced because of the reduced volume of air to be removed. Steam enters the shell through a slotted trough at the bottom of the shell, and air is exhausted through five 50-mm-diameter vent pipes located along the top. The retort drain valve is also open during the first portion of the venting cycle for condensate removal. Generally, the venting schedule is completed in 2–3 min [15].

24.4.3.5 Continuous Rotary Sterilizers

These systems are composed of at least one heating shell and one cooling shell and are designed for continuous handling of containers up to 600 cans/min. Containers from the sealing machine enter the first shell through a self-sealing rotary valve, which maintains the pressure within the shell. Each shell is designed with a "Spiral T" permanently attached to the wall, and a reel assembly with steps to hold the containers. As the reel turns, the containers follow the path of the spiral through the shell. After a container travels the length of the shell, it is either transferred to another shell by a rotary transfer valve or exits through a discharged valve. The venting and come-up procedures are performed without containers present in the vessel. This allows more flexibility in the design of the operating procedures compared to batch systems. Continuous rotary sterilizers are fitted with two or three 50-mm-diameter vent lines. The typical venting schedule calls for venting the units for 7 min and to at least 105°C with the vent valves wide open and the drain valve at least partially open. Alternatively, the air may be removed through the bleeders, drain, and purge lines rather than through the main vent lines. While air removal in this manner does take more time than traditional venting methods, it requires less operator involvement [11].

24.4.3.6 Cascading Water Retorts

The Steriflow cascading water retorts are designed and manufactured by Barriquand, Paris, France. The company manufactures both stationary and end-over-end rotational systems, and they have been installed internationally for processing foods and pharmaceuticals. Cascading water retorts utilize high-velocity superheated water to sterilize containers of food. Heating and sterilization are achieved by superheated water steaming at a high flow rate over the containers. An overriding air pressure is available for glass jars and flexible and semirigid containers to protect the physical integrity of the container and seal.

A schematic of the retort is shown in Figure 24.4. Water is heated by a welded plate heat exchanger located at the back or along the side of the retort in the middle. On the single-door units, the heat exchanger is located at the end opposite to the door; on the retorts with the door on both ends, the heat exchanger is located on the side of the shell and water enters at the top center of the retort. The superheated water is fed

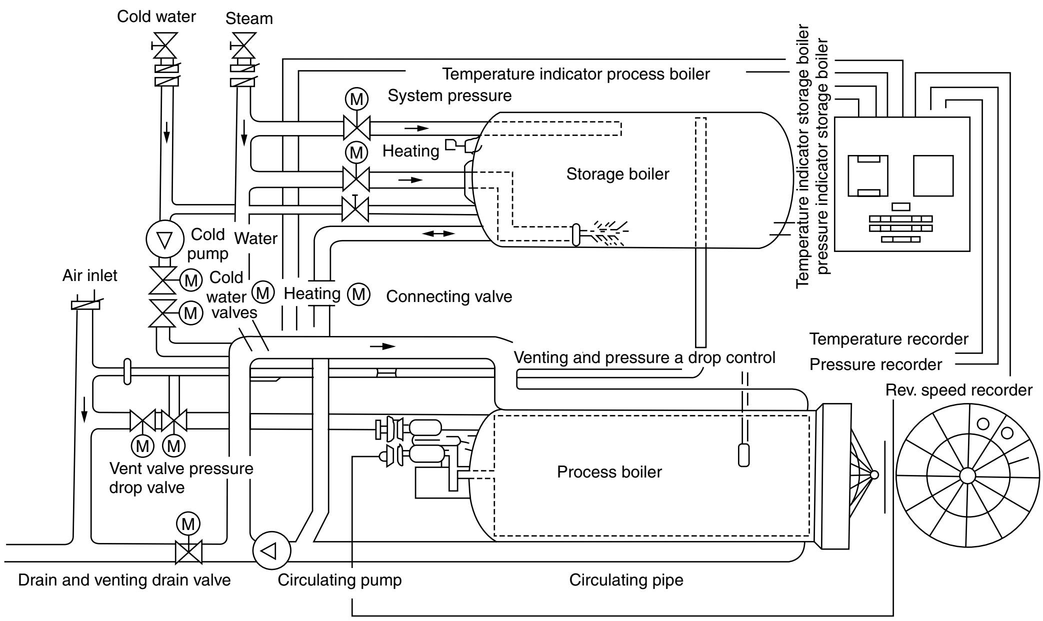

FIGURE 24.4 Horizontal circulating water retort. (From Perkins, W.E., *Introductions to the Fundamentals of Thermal Processing,* Sleeth, R.B., ed., IFT, Chicago, November 15, 1979, p. 82.)

into the retort through a distribution manifold. This water is continually recycled through the heat exchanger. In the heat exchanger, steam transfers its latent heat to the internal water, which is then showered from the distribution manifold over the product. The water cascades over the containers, not touching the sides of the shell and only a portion of the shell bottom. Therefore, it is not necessary to heat the entire shell during the come-up time, which can save energy. The same water is successively used for sterilizing and cooling the product. Therefore, the cooling is achieved with sterilized water, which means that chlorine does not need to be added without cooling water.

After passing over the containers, water passes through filters that keep debris, such as pieces of glass or product, from recirculating through the system. Both the water manifold and the filters are designed to be easily cleaned. The water manifold has a hinged gate at the end or ends next to the door, which can be opened and cleaned regularly. Since the opening for cleaning is opposite the water entrance, all debris is pushed to that portion of the manifold. This design is important to prevent the distribution holes from becoming clogged and perhaps reducing the water flow through a portion of the manifold. The bottom filters are also easy to remove and clean.

The first step is usually a preheat step or a tempering step in the case of glass jars. Usually, a certain minimum time is specified to get a more uniform come-up time for each cook. The second step is an overshoot of both time temperatures. This step is inserted to make sure that the mercury thermometer is registering the scheduled temperature at the beginning of the sterilization phase. This step is critical because the controlling probe and the mercury thermometer are not located in the same place; the mercury thermometer lags behind the controlling probe. The third step is the sterilization phase. For this step, it is recommended that the operating temperature be 1°C above the schedule retort temperature. The reason, common to most restarting systems, is to make sure that the mercury thermometer is at or above the schedule retort temperature during the entire sterilization phase. Time, temperature, and pressure are controlled. If the control in temperature drops below the set point, the timer stops until the correct temperature is achieved again. The fourth step is a pressure cool step to protect plastic or semirigid containers from bucking or glass containers from losing their lids during the first few minutes of cooling. The final step is an atmospheric cool. The actual time, temperature, and pressure for each program depend on factors such as the product formulation, container material and shape, entrapped air, product quality considerations, and steam, water, and air supplies [16].

24.4.3.7 Rotary, Full, Immersion, Hot-Water Sterilizers

The typical rotary hot-water sterilizer consists of two hot-water drums—the upper (storage) drum and the lower (working) drum. Sterilization of the food takes place in the storage drum after it receives preheated hot water from the storage drum. During rotation, cages turn in the same vertical plane within a rotating framework called the "rotor insert." Containers in the cages travel in end-over-end fashion in the hot water if loaded in a vertical orientation. Over pressure is usually supplied with steam in the storage drum, although steam or compressed air may be used with a slight installation modification.

As thermal energy in the lower drum is given up to the product, cages, and shell during the process, more energy is introduced into the working drum through an external steam mixing or distribution chamber. Steam is injected directly into the system's circulating hot water from the working drum through a diffuser located within the chamber. There is no direct steam injection into the shell in these units. Water is pulled from bottom or side ports spaced equally along the shell of the working drum, where it is pumped through the mixing chamber for heating. Water travels through top or side water inlet ports into the working drums in a "top-to-bottom" or "side-to-side" circulation pattern. Rotating the cages during come-up, heating, and cooling cycles helps to distribute thermal energy in the system, and reduces the come-up and cool-down cycle times.

Temperature and pressure are independently controlled in these systems. Temperature and pressure sensor connections for the recorder system are located in the thermometer pocket at the horizontal center plane of the working drum. A resistance temperature device (RTD), sometimes referred to as a "PT-100," is located near the right side of the front end of the storage drum and controls the storage drum water temperature. A second RTD controls temperature in the working drum and is positioned either before or after the mixing chamber in the circulation line or in the mercury-in-glass (MIG) thermometer well. After the heating phase is completed, a portion of the process water is pumped back into the storage drum, where it is heated to the required temperature set point for the next cycle. The circulation pumps are rated at approximately 400 gal/min with a 250 gal/min typical flow rate. The pumps use on/off, proportional valves, and valve actuators on the units [17].

24.4.3.8 "Hydrolock" Continuous Cooker/Cooler

Hydrolock is a continuous, agitating cooker/cooler for high-speed short-time sterilization of a wide variety of sizes and shapes of containers. The system is applicable for the processing of cans, glass jars, semirigid plastic and metal containers, and retortable pouches. It is also capable of processing plastic and metal containers with heat-sealed closures [13,18–21]. The basic parts of the system are (Figure 24.5) water lock, cooker/ cooler, chain carrier system, cooling system, and water circulating

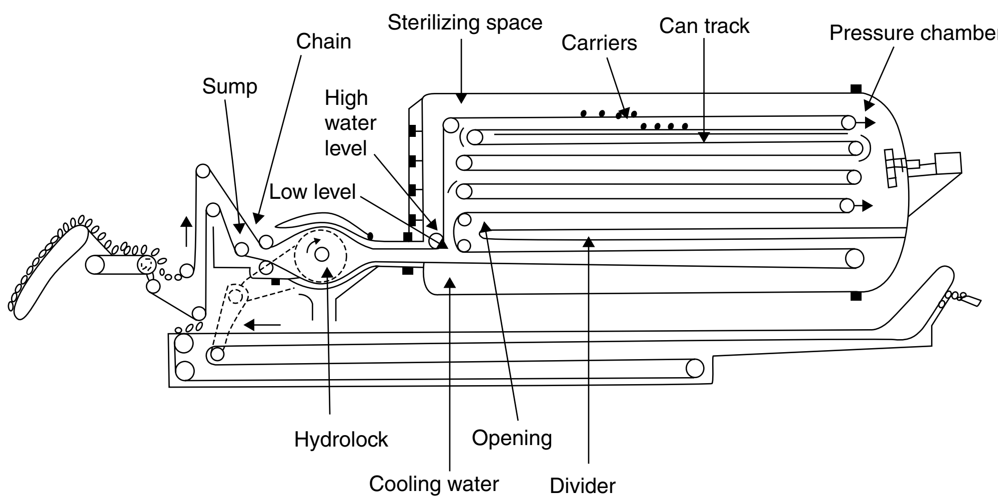

FIGURE 24.5 Hydrolock continuous cooker. (From Brody, A.L., *CRC Food Sci. Nut.,* 2, 187, 1971.)

system. Containers enter and travel through the process between two parallel conveyor chains. These chains enter and leave through water into a rotating pressure lock, sealed partly by water and partly by mechanical means. This facilitates preheating of incoming and precooling of outgoing containers. After loading through the lock, the containers are continuously conveyed through the steam chamber and finally into precooling water in which the conveyor passes. Containers exit through the same rotating pressure lock through which they entered and pass along a cooler conveyor. The hydrolock is equipped to provide overhead pressure during the cooling cycle to retain the container integrity. Final product cooling is completed in two passes of atmospheric cooling below the pressure vessel. Cans roll in shallow water in stainless-steel “pan” being pushed by stainless-steel rods attached at their ends to roller chains. Any heating medium can be used with the system: saturated steam, water, or steam–air mixture. When an overriding air pressure is required, as with glass containers, aluminum cans, plastic containers or flexible pouches, air is mixed with the steam by means of one or more turbo fans, which produce a homogenous mixture of the two gases.

24.4.3.9 Hydrostatic Pressure Sterilizer

This sterilization method is more commonly known as “hydrostatic sterilization” because the steam pressure in these units is maintained by water pressure. Hydrostatic cookers are continuous pressure cookers in which the operating pressure is maintained by water pressure. The schematic of the cooker is shown in Figure 24.6. Hydrostatic cookers have two components: water chambers and steam chambers. The temperature of the steam in the steam chamber is controlled by pressure produced by the water legs and can be regulated by moving the level of water in the leg [13,20,22]. Containers are

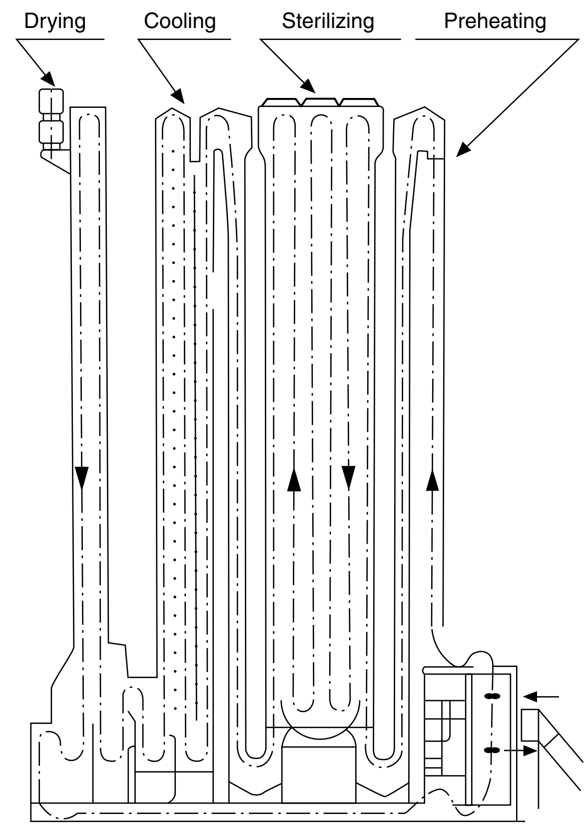

FIGURE 24.6 Hydrostatic pressure sterilizer (internal details). (From Perkins, W.E., *Introductions to the Fundamentals of Thermal Processing,* Sleeth, R.B., ed., IFT, Chicago, November 15, 1979, p. 82.)

conveyed into the cooker through a water leg at 80°C. This is the down traveling water leg and the container temperature begins to increase. As the containers move down this leg, it encounters progressively hotter water. In the lower part of this leg, the water temperature reaches about 100°C and then, near the water seal area next to the steam chamber, the water temperature is about 107°C. In the steam chamber, the can is exposed to a temperature of 115°C–130°C, the steam temperature being set to suit the product undergoing sterilization. Upon leaving the steam chamber, the can again goes through a water seal into water at a temperature of about 107°C where the cooling cycle commences, under pressure.

24.4.3.10 Hydrostatic Helix

The major advantage of the hydrostatic cooker is its compact size. The hydrostatic cooker has no mechanical valves or locks and thus can be a truly continuous motion retort. The helical pump or hydrostatic helix consists of a rotating coiled tube, in which each turn of the coil is charged at the intake partly with liquid and partly with air. The coil rotates about a horizontal axis. With no pressure at the discharge, the rotating coil may meter liquid at a rate proportional to its rotational speed. With a discharge backpressure, the liquid in each coil turn forms a series of additive hydrostatic legs. The hydrostatic head developed is a function of the number of turns of the helix and the diameter. When the coil is rotated, liquid can enter the coil by gravity flow for one-half turn only, when the first turn (acting as a manometer) is in the upright position. As the coil continues to turn through the next half turn, only air can enter because the manometer is inverted. Thus, equal volumes of liquid and gas are alternately introduced into the helix in a repetitive cycle. The helical pump thus operates with many short columns of gas [23].

24.4.3.11 Continuous Pallet Sterilizer

Hydrostatic sterilizers, because of their size and complexity of their water recirculation systems, are very expensive to construct and erect [13]. The continuous pallet sterilizer is essentially a continuous vertical retort through which cans are transported on pallets. The feed and discharge of the pallets is affected, without pressure loss, through venting locks. Each filled, unprocessed pallet load is conveyed by a rack and pinion arrangement into the lock. After the outside pressure door of the infeed lock is closed, steam is introduced, first at atmospheric pressure to purge air from the pallet and the chamber and thereafter under pressure to equilibrate the lock with the retort. After the venting–equilibration cycle, the pallet is moved forward until it is at the base of the retort. Pallets slowly ride upward on their four railroad-like wheels. The processed pallets leave the top of the retort through a “let-down” lock. The flexibility of a retort, in terms of the container type, is shared by the continuous pallet retort by virtue of the capacity of a round vessel to withstand much higher pressures than a rectangular hydrostatic sterilizer tower. Hot water sprays, overpressured with air and steam, with superimposed air pressure may be used as the sterilizing media. This equipment can be used for continuous processing of pouches, semirigid aluminum containers, institutional half steam table trays, and glass jars.

24.4.3.12 Flame Sterilizers

Infrared radiation as an indirect heat source was developed into flame sterilizers/cookers. Flame cookers attempt to increase the temperature differential between the heating source and the food product, and the rate of heat penetration. By increasing the rate of agitation, the probability of burn-on is markedly reduced [14,21,23]. Gas burners at 1100°C provide the heat source to impart the high-temperature short-time effect. The cans are placed in very close proximity (just a few millimeters away) to the burners and are kept in constant rotation, with a temperature differential within can and contents not exceeding 1°C. Thus, even fully lithographed cans may be heated without damage. There is no possibility to impart counterpressure, so cans must be fairly rigid to withstand internal steam pressure. With low viscosity products, extremely high rates of temperature increase (e.g., 0.25°C/s) of contents are possible. The unit depends on continuous axial rotation (about 120 rpm) to move the cans along the burners and obtain the internal turbulence. Some units have a steam preheat section. A schematic of the unit is shown in Figure 24.7 [24]. The steriflame units consist of three sections. The first one is a steam preheater, where the cans are heated to a temperature of approximately 100°C. In

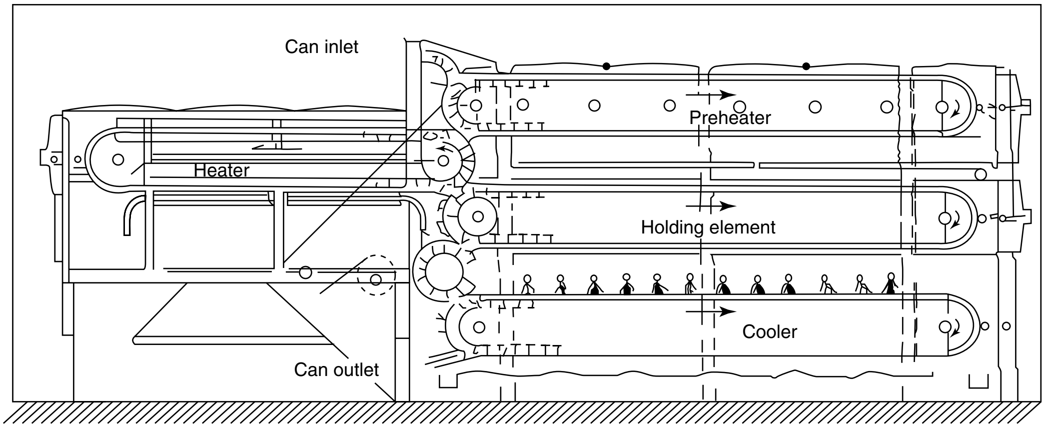

FIGURE 24.7 Flame sterilizer (longitudinal section). (From Beauvois, M., Thomas, G., and Cheftel, H., *Food Technol*., 15(4), 5, 1961.)

the second section, the cans roll through a series of open flames at 1100°C produced by specially constructed gas burners. Rolling motion of the cans increases the rate of heat transfer into the whole mass of the food. Next, the cans pass through an intermittently heated burner-holding section for about 4–5 min. Spray cooling follows the heating cycle. Total time elapsed in the cooker is generally less than that required for batch retorting.

24.4.3.13 Fluidized Bed Sterilization

The fluidized bed retort is a cooker in which sand or ceramic pellets are used as the heat transfer medium. The medium is kept hot and fluid by a flame underneath and an air stream. The particles behave much like boiling liquid. Cans move through the bed, meeting the same resistance as they would if the medium were a thick liquid receiving some abrasive effect from the particles [21]. The main advantage of the system is the control of uniform temperature. The process is continuous and several sizes may be sterilized simultaneously. The main disadvantages are the possibility of burning and discoloration of the can surface and damage of the can seals.

24.4.3.14 Hot Sterilization

Hot air with very high velocity (approximately 600 m/min) is employed to decrease the thickness of the nonturbulent air layer adjacent to the can surface. High-velocity air in excess of 150°C also creates a large temperature differential between the surface and the contents. Cans are axially rolled through to create forced convection within the can contents, thus reducing the possibility of burning or overcooking [14].

24.4.4 Temperature Distribution in the Retort Systems

Numerous critical tests must be performed to properly establish commercial sterility processes for any retorting application. The establishment of the "scheduled" (i.e., commercial sterility) process by a process authority depends not only on the ability of the food processor to properly control critical factors that relate to the preretort preparation of the product and the package in which the food is to be sterilized but also on those factors that specifically relate to the delivery of the thermal process to the packaged food. The manner in which the sterilizer is designed, installed, and operated is of critical importance. Failure to address these concerns will have direct and significant impact upon the lethality (sterilization value) designed into (and actually obtained in) the process.The FDA not only requires that temperature distribution tests be performed but also expects that certain data be collected and procedures followed. In addition, FDA [21CFR113.4 (b) (10) (i)] and USDA [9 CFR 318(381). 305(C)(2)(x)] regulations require that these data be evaluated by a "recognized competent process authority."

The traditional means by which acceptable process delivery conditions are verified is to use thermocouples, RTDs, or thermostats to generate time–temperature histories at preassigned strategic locations inside the sterilizer. These data are collected from "zero time" (when the heating medium first contacts the containers in the working drum) until a "to-be-determined time" at which all temperature-measuring devices meet the readings after sterilizer temperature indicating and recording devices. Most importantly, the time at which the lowest temperature lead meets the true "set point" temperature of the control program is critical. This exact time–temperature condition is the traditional process calculation reference point from which process hold times are determined. The "official reference instrument" against which all other sterilizer temperature control devices are adjusted is the MIG thermometer. All thermocouple lead readings must be able to compare to the MIG thermometer readings. Temperature distribution is, then, the uniformity of sterilizer temperatures and the stability of sterilizer temperatures at any given time during the entire process cycle, including the come-up, holding, and cooling phases.

Temperature distribution in batch, rotary, or hot-water sterilizers is affected by numerous conditions and system features. (i) Product initial temperature: lower initial temperatures usually lengthen retort come-up time and worsen temperature uniformity and stability. (ii) Storage drum temperature: the storage drum temperature is usually programmed to be 15°C–20°C above the targeted control set point in the working drum. If the hot-water drop temperature is too high, some semirigid and flexible containers may be damaged and the temperature gradients between the outside and the inside of the container cage position can become excessive. If the hot-water drop temperature is too low, too much heating in the working drum will then occur, which creates wide temperature gradients. (iii) Working retort venting: venting the working retort for too long in sterilization removes excessive energy from the system, extends come-up time, and forces more mixing chamber steam injection during the come-up phase. Too short venting time does not allow the storage drum/working drum filling step to occur properly and causes pressure control problems in the working retort. Ideally, a venting time of approximately ½ min/cage is appropriate (i.e., 2 min for a 4-cage 1100 mm unit). (iv) Working retort RTD location: the control RTD may be located before or after the mixing chamber in the water circulation line. When the RTD is located after the mixing chamber, the control device measures the hottest water in the circulation system; this results in less aggressive steam valve response and a slower but smoother ramp to temperature in the come-up phase. If the RTD is located before the mixing chamber, the control device measures the coldest water in the system, and the steam valve to the mixing chamber experiences a "response lag" by being fully open for too long. This causes a temperature overshoot at the end of the come-up period. (v) Container type and geometry: low-profile containers (cans, pouches, plastic trays, or bowls) must be filled into racking systems, which may create a considerable number of cage layers. Increased layers create increased resistance to heating medium flow. Generally, fully loaded large cylindrical containers exhibit shorter come-up time and improved temperature uniformity in all process phases. (vi) Container handling system: the cages, dividers, and racks for handling the containers must be designed to provide maximum cross-sectional open area (CSA) created by slots or perforations in the sides and bottoms of the cages. Spacer mats or divider sheets between layers of containers must be designed for maximum open area to enhance water flow past container surfaces. (vii) Rotational speed: generally, as rotational speed increases come-up time decreases and temperature uniformity and stability improve. (viii) Number of cages: the larger the unit and the greater the number of cages, the slower the come-up time and the greater the temperature differences throughout that the drum must be overcome. (ix) Retort design and operating environment: regardless of the retort manufacturer, it is advisable to perform temperature distribution studies in each batch, full-immersion, rotary hot-water retort. Design modifications, valve settings, blocked ports, and the number of retorts operating simultaneously in conjunction with other steam demand in the plant will affect test results and should be monitored closely. Rotary retorts to be added to an existing line must also be tested for temperature distribution [17].

24.4.5 Exhausting

The exhausting of containers for the removal of air should be controlled to meet the conditions for which the process was designed. Vacuum in canned foods may be obtained by preheating foods prior to closing. In producing vacuum by this means, the product may be heated prior to filling, or it may be heated both before and after filling. Heat in this case is employed to expand the product, expand and drive out the occluded and dissolved gases in the product, and reduce the air in the headspace before closure. The length of heating and the final temperature attained before closure has a very important relationship to the ultimate vacuum in the can. Heating may be accomplished by passing the filled can through a steam or hot-water exhaust box. It is common to refer to exhaust box treatment as "thermal exhaust" and to preheating before filling as "hot fill." Exhaust boxes are generally best adapted for canned foods that can readily be heated, such as brine- and syrup-packed fruits and vegetables. The major disadvantages of exhaust boxes are in their bulkiness and their large steam requirements. In mechanical vacuum closure by high-speed vacuum-closing machines, the filled cans while cold or at a rather low temperature are passed into a clincher, which loosely clinches the covers without forming an air-tight seal. The cans are then transferred through a suitable valve into a vacuum chamber, subjected to vacuum for a while in the vacuum chamber, sealed, and then ejected through another valve. Vacuums drawn on the machine while the cans are in the vacuum chamber may be varied over a wide range, depending mainly on the desired final vacuum in the can and also on the temperature of the liquid contents. This method of exhausting air from canned foods subjects the contents to a vacuum for a rather short interval of time before closure. Therefore, the air is withdrawn mainly from the headspace and only partially from the product itself, and proper adjustment of the headspace is necessary for proper performance.

24.4.6 Quality of Canned Foods

24.4.6.1 Plant Origin Foods

The purpose of heat sterilization is to extend the shelf life of foods while minimizing the changes in nutritive value and eating quality. Differences between the heating characteristics of microorganisms, enzymes, and sensory or nutritional components of foods are exploited to optimize processes for the retention of nutritional and sensory qualities. This is achieved in practice by a reduction in size or cross-sectional area of containers, agitation during processing, or aseptic processing. The extent of thermal processing, which a food receives, is dependent upon the composition and physical characteristics of the product and is the result of a combination of time and temperature. Physicochemical changes occurring during processing and storage are the factors that determine the product quality in terms of both its sensory properties and its provision of nutrients to the consumer. Reactions take place during both the process itself and on subsequent storage. Generally, the changes that occur during storage are slow, particularly when compared with those occurring in an equivalent unprocessed material, and it is on this basis that heat preservation is effective in providing materials outside their normal seasons and in a conveniently prepared, often formulated, form ready for consumption or reheating and then consumption. The physical and chemical reactions that occur during processing can be desirable or undesirable, and are often more significant and certainly occur much more rapidly than those during storage. The degree of heat processing varies according to the product. In turn, the changes that occur on processing are influenced by the time and temperature of the process, the composition and properties of the food material [25], and its environment [26].

24.4.6.1.1 Sensory Quality

The heat process itself has a major effect upon the quality of a food product and is responsible for a range of changes taking place. Starch gelatinization and structural protein denaturation have a direct influence on the texture of a food. Heat-induced reactions such as the Maillard reaction affect the color and flavor as well as the nutritional status of the food [27,28]. In general, changes that occur before the heat process are less important than those during or after processing since it is the manipulative and thermal procedures of food production that have the greatest effect on tissue damage and the resultant mixing of cell contents from different materials.

24.4.6.1.2 Texture

The tissue damage that occurs during the heat process of plant material is of two types. These are destruction or damage to the semipermeable cell membranes, and disruption of the intercellular structures with resultant cell separation [29]. The effects of these types of tissue damage are a loss in cell turgor and cellular adhesion, which give rise to loss of crispness and softening of the heat-processed product. Other major influences on the texture of heated foods arise from the denaturation of proteins. Even on relatively mild heating, conformational change affecting the tertiary structure of protein can be observed [30]. Denaturation of the proteins may follow. The hydrogen bonds maintaining the secondary and higher structure of protein rupture and predominantly random coil configuration occur [31]. This leads to considerable changes in chemical and physical properties of proteins due to losses in solubility, elasticity, and flexibility [30,32]. This mechanism also causes enzyme inactivation and breakdown of proteinaceous toxins and antinutrients. They cause turbidity leading to either a precipitate or gel, which will greatly alter their water-holding capacity and also lead to increased thermal stability [33]. In fruits and vegetables, softening is caused by hydrolysis of pectic materials, gelatinization of starches and partial solubilization of hemicelluloses, combined with a loss of cell turgor. Calcium salts may be added to blanching water or to brine or syrup, to form insoluble calcium pectate and thus increase the firmness of the canned product. Different salts are needed for different types of fruit (for example, calcium hydroxide for cherries, calcium chloride for tomatoes, and calcium lactate for apples) owing to differences in the proportion of demethylated pectin in each product.

24.4.6.1.3 Color

The color of a food product is determined by the state and stability of any natural or added pigments, and development of any coloration during processing and storage. Natural pigments are generally unstable compounds that are broken down on heating but whose stability is dependent upon many factors. In fruits and vegetables, chlorophyll is converted into pheophytin, carotenoids are isomerized from 5,6-epoxides to less intensely colored 5,8-epoxides, and anthocyanins are degraded to brown pigments. Anthocyanins are fairly heat-stable compounds but take part in a wide range of reactions, e.g., with ascorbic acid, sugar breakdown products, such as hydroxymethyl furfural, and other reactive phenolics, which bring about their breakdown [34]. Factors that accelerate degradation include high levels of oxygen in the product and storage temperature. Conversely, anthocyanins can be undesirable in a product and can be produced on thermal treatment of lencoanthocyanidin [35,36]. They give rise to defects such as very dark broad beans and red gooseberries. Other problems can occur with anthocyanin pigments due to the formation of metal complexes, for example, the bluing of red fruits and the pinking of pears when exposed to tin [37,38]. The flavonoid rutin, present in asparagus, can also form a complex with iron causing dark discoloration in lacquered cans where iron dissolution can occur [39] and in which the colorless tin complex is not formed.

Carotenoids are mostly fat soluble and are responsible for yellow, orange, and red coloration. They are unsaturated compounds and are therefore susceptible to oxidation, giving rise to off-flavor and bleaching. In addition, two types of isomerization can occur, namely, *cis–trans* isomerization and epoxide isomerization, which can give rise to lightening of the color. The temperature of storage is considered to have a greater effect on the isomerization than on the heat process itself. The two major groups of porphyrin-based pigments are chlorophyll and the heme compounds, both of which are very sensitive to heat. On processing, chlorophyll is converted into pheophytin with an associated loss of green color [39]. Several approaches have been taken to try to reduce the color loss such as adjusting the pH [40,41] and the use of HTST treatments. In the latter case, although improvements were observed after processing these were lost during storage [42].

Betalins are water-soluble pigments, which are susceptible to oxidation and loss of red color. Browning of heat-preserved beetroot products is an example where residual oxygen in the product or headspace causes the appearance of a chocolate brown color. Heat processing itself in the presence of oxygen has a major effect on the end product quality, and this is demonstrated by the comparison of products packed in plain tin-plate cans with the identical material processed in lacquered cans or glass jars. In the plain tin-plate container, dissolution of the tin during processing removes a major proportion of oxygen from the pack and little is available to react with the food. Some products such as pale fruits, tomatoes and tomato formulations, mushrooms, and milk products are particularly susceptible to such heat-induced oxidative changes. It has been demonstrated that a brownish color develops in beans dipped in tomato sauce packed in different container types [43]. Ascorbic acid is often used as an antioxidant and can be effective in improving color in certain products, e.g., mushrooms. It can be degraded to produce reactive compounds, which further react to form brown pigments.

24.4.6.1.4 Flavor

Generally, heat preservation does not significantly alter the basic flavors of sweetness, bitterness, acid, or salt. In fruits and vegetables, changes are due to complex reactions, which involve the degradation, recombination, and volatilization of aldehydes, ketones, sugars, lactones, amino acids, and organic acids. Major changes can occur in the volatile flavor components. One of the most important sources of volatile is lipid oxidation or oxidative rancidity. Three stages are involved: (i) initiation; (ii) propagation in which highly reactive hydroperoxides are formed, and (iii) termination. The initial uptake of oxygen is in the presence of catalyst, such as metal ions or metalloproteins, but can also be brought about by heat or light. The reaction does, however, have low activation energy (4–5 kcal/mol). The hydroperoxides formed take part in secondary reactions to give rise to a range of volatiles including aldehydes, ketones, and alcohols and it produces typical rancid or stale off-flavors.

Volatile flavor compounds are also produced via the Maillard reaction. Since the first scheme for the reaction was put forward [44], a great deal of research has been undertaken The reaction occurs during heating and extended storage, is influenced by water activity, with an optimum for flavor generation at intermediate values of around 30% water [45], and is accelerated by high pH and buffers such as phosphates and citrates [46]. The first stage of the reaction is fairly well defined and involves the condensation between carbonyl groups of the reducing carbohydrates and the free amino acids or protein, and rearrangement to produce amatory compounds. This leads to a loss of protein nutritional quality but does not affect the sensory properties significantly [47]. The second stage is very complex and gives rise to numerous products, many of them volatile and is responsible for many characteristic flavors and off-flavors in food materials. Loss of volatile constituents can also present problems in heat-preserved foods. The breakdown of essential oils in citrus products can result from oxidation. Packaging can also have a direct influence on volatile scalping.

24.4.6.1.5 Nutrients

Both physical and chemical reactions occur in heat-preserved foods, which influence nutritive value (Table 24.1). Physical factors such as the loss of soluble nutrients, or leaching, can be significant for

TABLE 24.1

Effect of Heat Processing on Major Nutritional Components

Nutrient	Effect
Dry matter	Loss of total solids into canning liquor Dilution Dehydration
Protein	Enzymic inactivation Loss of certain essential amino acids Loss of digestibility Improved digestibility
Carbohydrate	Starch gelatinization and increased digestibility No apparent change in content of carbohydrate
Dietary fiber lipids	Generally no loss of physiological value Conversion of *cis*-fatty acids to trans by oxidation Loss of essential fatty acid activity
Water-soluble vitamins	Large losses of vitamins C and B, due to leaching and heat degradation Increased bioavailability of biotin and niacin due to enzyme inactivation
Fat-soluble vitamins	Mainly heat stable Losses due to oxidation of lipids Losses due to leaching
Minerals	Possible increase in sodium and calcium levels by uptake from canning liquor

products in which there is a carrying liquid discarded before consumption. Chemical reactions include heat damage to labile nutrients such as vitamins. One of the most fundamental changes, which can occur in a heat-preserved product, is the movement of water and solids within the food material during processing, storage, and reheating. In a formulated product or a product in which the entire pack contents are consumed, such changes can be largely disregarded, from the nutritional point of view, in that they do not alter the total amount of the nutrients consumed. Products that are packed in liquor, which is discarded before consumption, often exhibit dilution, dehydration, or loss of total solid materials from the edible portion. Sterilized soya-meat products may show an increase in nutritional value owing to an unidentified factor that decreases the stability of the trypsin inhibitor in soybeans.

24.4.6.1.5.1 Proteins Heat preservation can lead to both desirable and undesirable changes in the nutritive quality of proteins. They are susceptible not only to heat but also to oxidation, alkaline environment, and to reaction with other food constituents such as reducing sugars and lipids oxidative products. The total amount of crude protein, generally, appears relatively unchanged due to heat processing [48,49] but can suffer from leaching into the liquid component of some products [50]. The crude protein levels, however, appear to be stable during subsequent storage of canned vegetables [48,49]. The changes occurring are associated with tertiary structure, functionality, chemical changes related to digestibility, and amino acid availability. Canning of potatoes also leads to loss of amino acids though this has been shown to vary depending on the specific gravity of the potato [51]. Lysine is again particularly vulnerable with a reduction in its availability of about 40%. Some of the losses found in canned potatoes may be due to the leaching of the protein into the brine [50], although the major cause of loss of amino acids on heat preservation is the Maillard reaction. Soybeans and many other legumes also undergo improved protein digestibility and bioavailability, especially of the sulfur-containing amino acids on heating due to inactivation of trypsin inhibitors and unfolding of the major seed globulins.

24.4.6.1.5.2 Vitamins The effect of heat preservation on vitamins is generally detrimental although mild heating conditions can have beneficial effects on the bioavailability of certain vitamins, particularly biotin and niacin. This is due to enzyme inactivation and the inactivation of binding agents [52]. The stability of vitamins varies under different conditions with vitamin C and thiamin being most susceptible to degradation through heating The fat-soluble vitamins are the more stable of the two sets, although these can be degraded by oxidation especially when heated. Loss of water-soluble vitamins during processing can be considerably higher. Vitamin C is the most labile of the vitamins and can be lost during storage of the fresh material, food preparation, washing, and blanching as well as by degradation on heating and leaching into a carrying liquor during the process. Studies on garden peas and carrots have shown that as much vitamin C can be lost on storage of the fresh produce for 7 days prior to cooking as that lost on canning. Much of the vitamin C lost during canning is leached into the canning liquor. Thiamin is the most heat sensitive of the B vitamins especially under alkaline conditions, and it is also susceptible to leaching during any washing or blanching stages. Thiamin, however, is less labile than vitamin C and retention of 60%–90% is usual in canning [53]. Folic acid and pyridoxine are also susceptible to degradation by heating and in the case of folic acid by oxidation. Canning of potatoes can lead to loss of vitamins up to 30% [54]. Both Riboflavin and niacin are relatively stable on heat preservation although riboflavin is very sensitive to light and will undergo degradation in the presence of both heat and light together [55]. Heat-preserved foods often require less cooking than fresh foods, and the differences in the vitamin content between the fresh and the processed food at the point of consumption can often be negligible. In canned fruits and vegetables, significant losses may occur in all water-soluble vitamins, particularly ascorbic acid/vitamin C.

24.4.6.1.5.3 Minerals Minerals are generally stable to most of the conditions encountered in heat preservations i.e., heat, air, oxygen, acid, or alkaline. Losses of minerals, however, can occur during processing, especially of vegetables, due to leaching into canning liquor. Conversely, certain minerals, for instance, sodium and calcium can be taken up by the food from the cooking or canning liquids.

Comparisons between fresh and canned vegetables have shown higher ash content in canned products in all cases. This is due to the uptake of sodium and to lesser extent of calcium from the brine. Between 15% and 50% of potassium can be lost primarily by leaching on the canning of vegetables. Slight leaching of zinc and negligible changes in iron content occurs during processing. Heating has been seen to increase the bioavailability of iron in spinach and the presence of fructose also leads to an increased iron bioavailability [56].

24.4.6.1.5.4 Carbohydrates Carbohydrates are less susceptible than most other food compounds to chemical changes during heat preservation. The levels of total and available carbohydrates in vegetables have been found to be very stable on canning and subsequent storage of the canned vegetables. However, there are some effects of heat on various carbohydrates. The effect of sugar on protein and iron bioavailability, and the relationship between starch, texture, and palatability are more important. Gelatinization of the starch also aids digestibility of foods. A good example of this [54,57] is the potato, which in raw state is largely indigestible. The exact effect of heat preservation on various types and constituents of dietary fiber has not been fully investigated. Cellulose, the main constituent of dietary fiber, hemicelluloses, and pectins are together responsible for structure and texture in plant foods [58,59] and can be disrupted by heating, which leads to a softening of the food and increased palatability as discussed earlier, generally, without any loss in the physiological value of the dietary fiber. Overheating can lead to a breakdown in the cells, enabling water-soluble nutrients, for instance, certain minerals, vitamins, and pectins to be leached out. Although dietary fiber is considered to be largely unaffected by heat processing, the exact relationship between time–temperature conditions, dietary fiber breakdown, and the extent of nutrient loss due to fiber breakdown requires further study.

24.4.6.1.5.5 Lipids Lipids, especially the unsaturated lipids, are prone to oxidation when heated in the presence of air or oxygen, resulting in losses in nutritional value of the food product. Although the major effect of lipid oxidation is in the flavors of foods, oxidation can lead to a conversion of the natural *cis*-fatty acids to *trans*-fatty acids [56]. The digestion and absorption of *trans*-fatty acids is comparable to that of the *cis*-fatty acids and their nutritional value as an energy source is not affected. However, *trans*-fatty acids do not generally possess essential fatty acid activity, i.e., as precursors of prostaglandins and thromboxanes. This activity is dependent on a *cis* 9, *cis* 12 methylene interrupted double bond system, but provided that sufficient linoleic acid is consumed, the *trans*-fatty acids do not appear to inhibit essential fatty acid metabolism [60,61]. The oxidation of lipids has also been implicated, as previously noted, in the loss of protein quality and can inhibit the activity of the fat-soluble vitamins A, D, and E as well as vitamins C and foliate. The oxidation of fats in processed foods, however, can be controlled by the exclusion or minimization of oxygen and the use of antioxidants. The effects of heat preservation on the nutritional value of fats can therefore generally be considered as negligible.

24.4.6.2 Animal Origin Foods

24.4.6.2.1 Color

The time–temperature combinations used in canning have a substantial effect on most naturally occurring pigments in meat foods. The red oxymyoglobin pigment is converted into brown metmyoglobin, and purplish myoglobin is converted into red-brown myohemichromogen. Maillard browning and caramelization also contribute to the color of sterilized meats. However, this is an acceptable change in cooked meats. Sodium nitrite and sodium nitrate are added to some meat products to reduce the risk of growth of *C. botulinum*. The resulting red-pink coloration is due to nitric oxide myoglobin and metmyoglobin nitrite. Loss of color is often corrected using permitted synthetic colors.

24.4.6.2.2 Flavor and Aroma

In canned meats, there are complex changes (for example, pyrolysis, deamination and decarboxylation of amino acids, degradation, Maillard reactions and caramelization of carbohydrates to furfural and hydroxymethylfurfural, and oxidation and decarboxylation of lipids). Interactions between these components produce more than 600 flavor compounds in 10 chemical classes [62,63]. Other volatiles have been identified as having a significant effect on the flavor of foods, and perhaps one of the most dramatic is the development of "catty taint." This is an extremely unpleasant and potent odor produced by the reaction of unsaturated ketones, notably mesityl oxide, with natural sulfur-containing components of the food [62,63]. Heating is essential in the formation of the taint and incidents have been widespread due to the diverse availability of the unsaturated ketones. Examples include processed meat products using meat from cold store, painted with a material containing mesityl oxide as a solvent contaminant [64], canned ox tongues, which had been hung on hooks coated with a protective oil [65], and pork packed in cans with a side seam lacquer, which had been dissolved in impure solvent [65,66].

24.4.6.2.3 Texture

In canned meats, changes in texture are caused by coagulation and a loss of water-holding capacity of proteins, which produces shrinkage and stiffening of muscle tissues. Softening is caused by hydrolysis of collagen, solubilization of the resulting gelatin, and melting and dispersion of fats through the product. Polyphosphates are added to some products to bind water. This increases the tenderness of the product and reduces shrinkage. Small changes in the viscosity of milk are caused by modification of K-casein, leading to an increased sensitivity to calcium precipitation and coagulation.

24.4.6.2.4 Nutrients

Canning causes the hydrolysis of carbohydrates and lipids, but these nutrients remain available and the nutritive value of the food is not affected. Proteins are coagulated, and in canned meats, losses of amino acids are 10%–20%. Reductions in lysine content are proportional to the severity of heating, but rarely exceed 25%. The loss of tryptophan and to a lesser extent, methionine, reduces the biological value of the proteins by 6%–9%. Vitamin losses are mostly confined to thiamin (50%–75%) and pantothenic acid (20%–35%). However, there are large variations owing to differences in the types of food, the presence of residual oxygen in the container, and methods of preparation (peeling and slicing) or blanching. In some foods, vitamins are transferred into the brine or syrup, which is also consumed. There is thus a smaller nutritional loss. Heat sterilization of meat leads to a reduction in digestibility of the meat proteins and damage of amino acids, especially the essential sulfur-containing amino acids and lysine, with 10%–15% losses in beef [67]. The heat preservation on the quality of foods has two important effects. (i) Many of the changes (sensory or nutritional) that occur during the thermal process are not restricted to heat-preserved foods. In many instances, the process replaces the conventional cooking, which the food receives prior to consumption. Reheating the heat-preserved food is a relatively mild treatment, which does not significantly affect the quality. (ii) heat-preserved foods provide the consumer a wider choice of sensory experience and nutritional requirements without constraint of seasonality and the burden of preparation.

24.4.7 Packaging of Canned Foods

Under the regulations, "hermetically sealed container" means a container that is designed and intended to be secure against the entry of microorganisms and maintain the commercial sterility of its contents after processing. The container is an essential factor in the preservation of foods by canning. After canned foods are sterilized, it is the container that protects the canned food from spoilage by recontamination with microorganisms. It is then most important for the success of the canning operation to use good-quality, reliable containers and properly adjusted closing machines. Thus, the seams and closures produced will be within the guidelines necessary to prevent access to microorganisms into the container during the cooling operation and during the shelf life of the product.

24.4.7.1 Tin-Plate Cans

Today the choice is from among [21]: (i) tin-plate body and ends, (ii) tin-plate body and one end, aluminum convenience end, (iii) three-piece aluminum can (rare, but available and used, with adhesive side seam, for alcoholic cocktails), (iv) tin-free steel with tin end, tin-free steel end, aluminum end, or a combination,

(v) tin-free steel body, (vi) adhesive joined side seam, (vii) welded side seam, (viii) draw and iron two-piece aluminum can, (ix) conventional top chime, (x) neck-in top flange so that chime is flush with body, (xi) draw and iron two-piece steel cans not commercially available except in small sizes for aerosol cans.

24.4.7.1.1 Two-Piece Cans

All the major and secondary can making and can-handling equipment manufacturing firms produce two-piece draw and iron can. One of the significant commercial cans is a very small 28–57 g (1–2 oz.) unit. It is evident that a two-piece steel can would eliminate the long seam and one double seam, and thus preclude two sources of potential leakage. The amount of metal used would be reduced below that used for a three-piece. Two-piece steel cans offer the advantages of a two-piece aluminum can at a lower price [21].

24.4.7.1.2 Three-Piece Cans

Three-piece "sanitary cans" consisting of a can body and two end pieces are used to seal heat-sterilized foods hermetically and also for other food products such as powders, syrups, and cooking oils. Presently, the three-piece cans are being widely used, and other cans such as two-piece cans, aluminum cans, and other flexible containers are slowly replacing them [21].

24.4.7.1.3 Aluminum Cans

The main application of aluminum cans is where inherent advantage can be realized over the tin plate such as lower shipping expense, freedom from food and can black-sulfide discoloration or rust, easier puncture opening, and where special easy opening features are desirable [21]. Steel cans are so well established in the canning industry that exceptionally good reasons are required before a change of material is contemplated. The future use of aluminum for cans, for processed food use, to a great extent depends on the price at which it may be sold to the users, relative to that of an equivalent steel can. Aluminum cans offer advantages of product quality and economy for the canning of certain food products. The use of easy-open lids is also a significant point, which has a strong appeal. Aluminum cans do not rust and their appearance, always bright, can be an important sales argument. An important advantage of aluminum cans is that they are lead free. Nevertheless, aluminum cans dent easily, abrade, and are not interchangeable with steel cans.

24.4.7.1.4 Collapsible Tubes

Aluminum may also be used in the form of collapsible tubes for packaging processed food products. Sterilized foods packaged in collapsible tubes for the feeding of astronauts and high-altitude aviators have been developed. The aluminum tube fitted with a hollow handled plastic spoon, which can be attached to the neck of the tube, should make a desirable and convenient package for feeding infants or bedridden patients [21].

24.4.7.1.5 Composite Cans

Another development is the foil/fiber can, more commonly called the composite can. It was used earlier for refrigerated biscuit dough. This material is now being used for frozen concentrated orange juice. The composite spiral can made of fiber/polyethylene/aluminum foil and has the major share of the juice and juice drink frozen concentrate canning. Composite cans have been successfully employed for shortening and with polyvinylidene chloride coating for vacuum packaging of roasted and ground coffee. There has been considerable publicity on the use of composites, for beer, hot fills, pasteurized, and even retorted foods [21].

24.4.7.2 Glass Containers and Metal Closures

24.4.7.2.1 Containers

The chemical and physical properties of glass make it an ideal container material for canned foods. It is a chemically stable material. However, in long-term storage against aqueous solutions, and most particularly against acid foods, a very small amount of alkali may extract from the glass, and in some instances, lesser amounts of SiO_2 or silica. These materials are commonly found in all food products; therefore, the glass container is considered quite inert and is nonadditive in the packaging of most, if not all, food products. It does not support or facilitate microbial growth on its surface, and like metal it is impermeable to gases, liquids, bacteria, and odors. One very apparent characteristic of the glass container is its transparency. While the visibility of the product contained is attractive to the consumer, it does impose restrictions on the canner as to the appearance of the product [68]. Commercial glass jars are formulated and designed to withstand the thermal shocks normally encountered in the canning process. The maximum temperature shock as measured by the temperature differential is generally 45°C. However, they can withstand wider temperature differentials, but under certain conditions. They are also designed to resist the mechanical shocks normally encountered in a well-designed and, maintained filling and packaging line. Their resistance to vertical pressure allows the application of various capping methods and stacking [68].

24.4.7.2.2 Metal Closures (Caps)

The various metal closures that are used in food canning are [68]: (i) twist-off or Eurotwist, (ii) Eurocap and EurocapX, (iii) pry-off, (iv) press-twist (PT), and (v) deep-press (DP). The metal closure along with the sealant is designed specifically for each type of glass finish to permit the attachment of a proper seal and efficient closure. For shipping and storage, the nonstackable caps are packed in bulk in cartons, with or without plastic liners, and the stackable caps in overwrapped rolls. The cartons are palletized and either shrouded or strapped. Each carton should be labeled to identify the contents and manufacturing lot. Staples should not be used to close the cartons because they may contaminate the closures [68].

24.4.7.3 Retortable Pouches

Thermally processed laminate structures are made out as retortable pouches. Shelf life, toughness, resistance to puncture, and ability to withstand high temperature are some of the important characteristics for selecting materials for flexible containers. The retort pouch was designed to be a package that would offer the shelf stability of canned foods with the quality of frozen foods. The material configuration of this package has been enhanced over the past several years to bring the pouch even closer to this goal. Typically, the retort pouch consists of a 0.5-mil polyester film laminated to 0.000035 or 0.0007 in gauge aluminum foil. This is in turn laminated to a 3-mil modified polypropylene film. Each of these three substrates plays an important role in finished package [69]. On the outside, the polyester provides toughness, abuse resistance, and printability. The package can be printed with colors ranging from a simple one with two color instructions to full-color vignettes of the food product. The actual printing is applied to the "reverse" side of the polyester film, trapping the inks between laminates to protect against scuffing. In the middle, the aluminum foil is the key to the retort pouch's being a completely shelf-stable food package, with no expensive freezing or refrigeration required. Aluminum is the lowest cost barrier to light, moisture, oxygen, and microorganisms. On the inside, the polypropylene film performs two important functions: first, it is inert and does not react with food, so that virtually the entire range of processed foods can be packaged in this one basic material. Second, it provides exceptionally strong heat seals that can withstand the pressure and temperature demands of retorting and contribute to a shelf life at least equal to that of cans [69].

24.4.7.3.1 Advantages of the Pouch

The retort pouch is an integral component of the food distribution system with food product quality and package convenience. The thin profile and increased surface area of the retort pouch permit rapid heat penetration and much more efficient processing than with cans. Typical time savings in the cook cycle of a retort process are up to 40%. This reduction in heat exposure results in improved food product quality—better taste, color, and texture than similar products processed in cans. There is also a potential for nutritional advantage as well, particularly where heat-sensitive nutrients are concerned. Packing a food in the retort pouch results in better-tasting product [69].

24.4.7.3.2 Advantages to the Consumer

From the consumer's viewpoint, the retort pouch is certainly the most convenient food package. Completely shelf-stable, retort-pouched foods may be stored in the cupboard along with other dry goods. Foods packed in retort pouches are sterilized and are ready to eat. Foods may be heated to serving temperatures before consumption. This can easily be accomplished by heating in boiling water for about 5 min. In this manner, a variety of foods may be conveniently prepared at the same time, with no messy pots and pans to scrub. With the advent of the microwave oven, the true convenience of food preparation in boiling water is now less utilized. All that boiling water does to a retort-pouched food product is heat it; since the temperature of the boiling water is reasonably constant, the pouch can remain in the pot for 6–8 min and still deliver a satisfactory result, while the consumer is occupied elsewhere. In addition, retort-pouched foods are easily prepared in microwave ovens. The contents are poured onto the serving plate and heated for about 1–2 min. The added stiffness of the aluminum foil makes the retort pouch easy to tear open, using the notches provided. Disposal of empty pouches after use is extremely convenient, as they are easily flattened and contain no dangerous sharp edges. This is particularly important in food service operations, where No. 10 takes more space [69].

24.4.7.3.3 Advantages to the Processor

Retort pouches offer important advantages to the processor by cost savings. Packaging materials cost for retort pouches are lower than for steel cans (comparing total package cost for a pouch and outer carton versus a three-piece steel can, lid, and label). A roll of retort pouch stock takes up 85% less space than the equivalent number of empty cans, providing warehouse space savings on the front end of a packaging operation. The retort pouches offer savings in freight because it is lighter in weight than other packages. For example, 1000 numbers of 225 g (8 oz) steel cans weigh approximately 50 kg (109 lb), compared to just over 6 kg (12 lb) for equivalent pouches. With lighter package weight, more food product can be shipped per truck load in unrefrigerated trucks. One of the principal advantages of the retort pouch is that the package is sized to the food product, not vice versa as with cans. Thus, where liquid, or brine, is not essential to the food product, much of it may be eliminated, offering even more cost and freight savings [69].

24.4.7.3.4 Advantages to the Retailer

Retort pouches can be merchandized anywhere in the store near the checkout counter or in end aisle displays. Initially, retort-pouched foods were marketed in paperboard cartons, for puncture resistance and product display. Soon, pouches may be marketed without cartons, printed with full-color illustrations, and merchandised on pegboards or special shelf units [69].

24.4.7.3.5 Other Advantages

An environmental impact study has shown that the retort pouch, from package manufacture to consumer use, required less energy than canned food (in cans or glass) or frozen food. The pouch also made a more passive contribution to the waste-disposal systems than other packages [69].

24.4.7.3.6 Retort Pouch Technology

A summary of the state of the retort pouch technology and its various aspects can be explained under the following headings [70]: (i) Films—for temperature range of 116°C–124°C, 9–25 micron polyester/9–25 micron foil/75 micron polyolefin (modified polyethylene or ethylene-propylene copolymers and blends) can be used. For temperatures up to 138°C, 12 micron polyester/9 micron foil/15 micron oriented nylon-6/50 micron polypropylene can be used. (ii) Products—over 100, ranging from commodity vegetables to "ready meals." (iii) Package design—flat four seal, ranging from 10 to 100 mm × 5 to 175 × 20 mm for 150–300 g (5–10 oz.) contents to 300 mm × 450 mm × 25 to 12 mm for institutional packs, for 2.5–3.5 kg (5–7 lb) contents. With folding carton or polymer bag over wrap. (iv) Pouch packaging equipment—from roll stock, intermittent motion packager for 25–60 pouches per minute with steam flush and closure sealing, or could incorporate in-line vacuum sealing without transfer to separate machine. From roll stock, continuous motion packager for 250 pouches per minute. From preformed pouches, filler sealers for 25–60 per minute can with squeezing action or steam flush for air removal. (v) Retorts—horizontal batch, water or steam-air cook, modified to assure uniform distribution of heating media; use of retort racks, with separate heating media accumulation tank; suitable for high-temperature (135°C) cooks.

Continuous horizontal or vertical retorts for water or steam-air can also be used. (vi) Cartoning—standard folding carton equipment.

24.4.8 Energy Aspects of Canning

The energy analysis of the operation of the food sterilization unit is useful in two respects. First, it provides quantitative information on energy requirements of use in designing the energy generating and delivery system; and second, it evaluates the modes of energy loss. Information obtained from the energy analysis can be used for quantifying energy conservation practices [71]. Energy required for manufacturing, transporting, and processing was estimated for two alternative systems (canning line and retort pouch line), each capable of producing about 45 metric tons of processed spinach per 8 h shift.

The following conclusions were drawn. (i) Container manufacturing required more than 80% of the energy required in each system. (ii) A pouch processing line will have much higher electrical requirements than a comparable canning line. However, costs associated with the electrical use are small compared to total costs. (iii) The total energy requirement for a retort pouch packaging system is significantly less than that for a can packaging system. (iv) Container and energy costs for a retort pouch packaging system are significantly lower than those for a comparable can packaging system. (v) A comprehensive economic analysis must be conducted before a decision to adopt retort pouch processing technology can be made.

A dominant factor influencing total energy use in the canning industry is the heat requirements of food sterilization. The continuous cookers used in canneries are typically more energy efficient than batch processing in retorts [72]. Energy consumption rates in operating various sterilizing equipment have been compared. The energy requirements of a rotary pressure retort, a rotary atmospheric retort, and a flame sterilizer were estimated and the overall heating efficiency was 47.7%, 31.2%, and 27.5%, respectively [73]. The comparative costs of the heat required for sterilization of canned products by different equipment (Table 24.2) have been reported. The thermal energy balance of a stationary retort was studied [75]. Only 16.7% of the steam supplied was used in heating the cans and contents and the remainder was lost during venting (36.4%), heating of the retort and crates (16.4%), along with the condensate in the bottom of the retort (11.2%), and through radiation (19.3%). The study indicates significant loss of steam during venting. Data from different canneries showed steam consumption to be quite consistent for the retorting operations, averaging 3 kg/min of steam per 24 numbers of No. 2 cans. During venting, the peak of steam consumption may vary between 1135 and 2720 kg/h for a standard 3–4 crate retort, depending upon the size of the steam inlet line. The peak demand drops off to an operating demand of 45–68 kg/h after the vent valve is closed and the retort reaches operating temperature. A novel fluidized-bed retort [76,77] involves heating and cooling of cans in a fluidized bed of sand or other granular material of high density. Fuel savings can be significant with a fluidized-bed retort, since the heating medium (usually air) does not go through a phase change and recycling of the heating medium improves the energy efficiency of the equipment.

TABLE 24.2

Energy Costs Required for Thermal Processing of Canned Foods by Different Equipment

Processing Equipment	Comparative Costs of Heat		
Static retort	100[a]	100[b]	100[c]
Continuous rotary atmospheric retort	–	–	64
Continuous rotary pressure retort	–	–	46
Hydrostatic retort	20	56	–
Fluidized-bed retort	–	38	–
Microwave retort	1230	–	–
Flame sterilization	56	–	88

[a]= Values in this column from Ref. [74].
[b]= Values in this column from Ref. [76].
[c]= Values in this column from Ref. [73].

24.5 Aseptic Processing

24.5.1 Introduction

The development of the HTST processing methods for sterilizing in a continuous flow has brought about the need for aseptic packaging of the product. It is only through the use of aseptic packaging that the benefits of HTST treatment can be fully realized. Aseptic packaging will exhibit the greatest quality improvement over conventional canning when viscous low-acid products are processed. Many products can be commercially sterilized prior to packaging by continuous processes so that their organoleptic and nutritional quality is not significantly affected. Products such as puddings, sauces, dips, and pastes are currently aseptically processed. In the techniques applied to aseptic packaging, continuous heat exchangers can be designed so that any temperature profile may be applied. Aseptic packaging of foods is a process that enables products, sterilized in bulk or on-steam, to be filled and sealed into sterile containers, under aseptic conditions. There are two reasons for its use: (a) to enable containers to be used that are unsuitable for in-package sterilization and (b) to take advantage of HTST sterilization process, which is thermally efficient and generally give rise to products superior in quality compared with those processed at lower temperatures for longer times [78].

Application of the aseptic process involves (a) sterilization of the product, (b) sterilization of the packaging material, and (c) maintenance of the sterility during the filling and sealing operations. The advantages of aseptic packaging of food products are that it provides a higher quality product. A wide variety of packaging materials of different sizes and shapes can be used. There is minimum handling of the containers during the sterilization process. Also, it provides a high surface area for efficient heat transfer [79]. Aseptic processing and packaging, however, has limitations and it does not offer advantages with all products. Some of the disadvantages that are generally cited are large capital investment, applicability to limited range of products, requirement of a relative homogenicity of the fluid, and a need for sophisticated instrumentation [79].

24.5.2 Sterilization Systems

The production of a sterile product by continuous-flow sterilization involves (a) heating the product by passing it through a suitable heat exchanger to raise it to operating temperature, (b) passing the product through a holding section for a predetermined time to effect sterilization, and (c) cooling it to a temperature of 35°C or less prior to aseptic filling. The heat exchange process is limited to liquids containing small particles with a cross section of less than about 8 mm. For sterilization of large pieces, special equipment is required [80,81]. The ideal system would raise the temperature in the heat exchanger to the required value, thus eliminating the holder tube requirement. It is not possible to use a sufficiently high temperature and short residence time for this purpose with many products since (a) viscous products are difficult to heat uniformly and evenly to the operating temperature, (b) the presence of small particles makes it desirable to impose an unheated section to equilibrate temperatures, (c) the products may contain heat-resistant enzymes that are more likely to survive processes at the top end of the temperature range, and (d) the criticality of the process makes control difficult. The key components of the aseptic systems are the timing or metering pump, product heater, holding tube, cooler, and back-pressure valve. The type of aseptic processing equipment selected is dependent on the pH, the viscosity or consistency of the product, and on whether it contains particulate and their size.

24.5.3 Processing Equipment

24.5.3.1 Infusion Sterilization

24.5.3.1.1 Steam Injection Sterilization

This is the most rapid method of heating the product and facilitating the attainment of sterilization temperature within seconds. Combined with the rapid method of cooling by injection of the hot product into a vacuum chamber and evaporation of an equivalent amount of water, a very high quality product is obtained. The method is combined usually with heating and cooling in heat exchangers to the low temperature range (80°C) [82].

24.5.3.1.2 Liquid Infusion into Steam

This system involves infusion of a thin film of liquid into a steam atmosphere, facilitating rapid heating. Cooling is also achieved by infusion of the liquid into vacuum chamber. The system is a versatile processing method designed primarily to heat and cool fluid foods within seconds. It produces the fastest heating methods, and this minimizes flavor changes and product damage normally associated with high processing temperatures. It is especially important for low-acid products, which require sterilizing up to 150°C. The system may be prepiped and packaged or field assembled to meet specific plant space requirements. Acquisition costs for infusion heating systems are low when high flow rates are being processed. There are few moving parts and the service costs are low. However, the method is suitable for particle-free liquids only. The heat recovery efficiency is only about 50%.

24.5.3.2 Tubular Aseptic Sterilizer

Tubular aseptic sterilizing is an indirect heating/cooling method that uses stainless-steel coiled or straight tubular heat exchangers. The tubing diameter is relatively small compared to product flow. As a result, extremely high-flow velocities within the tubing maximize turbulence. High turbulence induces rapid heat transfer [21,82]. The tubing diameter is suited to the product flow and viscosity. Tubes are fabricated into coils or bundles, and placed along with special media baffles into stainless-steel jackets. Hot water, steam, or cold water pass through these jackets to heat or cool the product flowing within the tubes. A series of horizontal tubular heat exchangers and a vertical holder tube heat hold the product to the required sterilizing temperature and time. For low-acid products, 150°C with a holding time of 2–4 s is used. High-acid product would normally be heated to around 95°C and held for approximately 30 s. From the holding tube, the product flows to another series of vertical tubular heat exchangers for cooling. This system provides high heat transfer rates and a scrubbing action that reduces "burn off" or fouling in the tubes, resulting in a very short processing time. This helps to preserve the natural flavor of the product. The system has considerable flexibility in the range of products they can handle and the temperature range at which a specific product can be processed. They are completely self-contained, requiring only the product and utility hookups to be made during installation. There are no gaskets to replace on the high-temperature side. Most systems are available with regeneration as an option. Regeneration may be as high as 85% depending on flow rates, product characteristics, and the regeneration option used.

24.5.3.3 Swept Surface Sterilizer

This type of heat exchanger is similar to the tube heat exchanger but is provided with a central rotating shaft carrying a scarping device for the heated surfaces. This prevents burning and fouling of foods at the surface and also provides a mixing action. The system is used when a viscous material or that containing small, discrete particles is to be processed. Swept surface sterilizing is an indirect heating/cooling method. With the continual removal of the product from the cylinder wall, the product film is reduced to an absolute minimum, permitting long processing runs without product build up on the heat exchanger wall [82]. Heat-sensitive products can be processed and the system is versatile for aseptic processing of different products. Products can be processed over a broad temperature range and viscosity with or without particulate. The various horizontal and vertical configurations allow this form of heat exchanger to be adapted to specific systems or plant requirements. It may be used in series with other types of heat exchangers for products such as starches that might increase in viscosity due to processing.

24.5.3.4 Plate Sterilizer

Plate heat exchanger (described in the pasteurization section) can also be used for aseptic processing.

24.5.4 Packaging Systems

Aseptic packaging refers to the filling of a cold, commercially sterile product under sterile conditions into a presterilized container and closure under sterile conditions to form a seal that effectively excludes microorganisms. Aseptic literally means the exclusion of microorganisms from the environment. Aseptic processing is really a method of packaging because foods are not sterilized or cooked or otherwise altered by aseptic methods. Rather, they are handled or moved by aseptic methods to assure they retain the microbiological quality with which they started. In general, aseptic packaging is coupled with HTST or UHT methods of food sterilization, and the two processes are joined in a complete system to produce what is referred to in the trade as aseptically processed foods. However, the total aseptic equipment is not an actual integrated system and the processor must purchase the sterilizer and the aseptic packager as separate units and then tie them together.

24.5.4.1 Sterilization of Packaging Materials

Package sterilization has been accomplished by using a number of methods and its combinations [83]. The most common methods are based on the use of (a) superheated system, (b) hot, dry air, (c) hydrogen peroxide, (d) combination of hydrogen peroxide and ultraviolet light, (e) combination of hydrogen peroxide and heat, (f) heat of the coextrusion process, and (g) irradiation by gamma rays. These methods are given in Table 24.3 [84].

24.5.4.1.1 Superheated Steam Systems

In this system, sterilization of the container and its closure is accomplished by the application of heat using superheated steam. The advantage of this system is that it can achieve high temperatures at the atmospheric pressure; however, microorganisms are more resistant to superheated steam than saturated steam.

24.5.4.1.2 Dry Hot Air Systems

Hot air sterilization has similar advantages and disadvantages of superheated steam. There are currently no units of this type utilized in the production of low-acid foods, but the equipment has been used for the production of juices and beverages.

24.5.4.1.3 Hydrogen Peroxide Systems

A number of systems utilize hydrogen peroxide in combination with heat and other adjuncts. In this system, the packaging material is not metal and it comes in rolls rather than in preformed containers.

TABLE 24.3

Methods for Sterilizing Aseptic Packages

Method	Application	Advantages/Disadvantages
Superheated steam	Metal containers	High temperature at atmospheric pressure; microorganisms are more resistant than in saturated steam
Dry hot air	Metal or composite juice and beverages containers	High temperature at atmospheric pressure; microorganisms are more resistant than in saturated steam
Hot hydrogen peroxide	Plastic containers, laminated foil	Fast and efficient method
Hydrogen peroxide/UV	Plastic containers (preformed cartons)	UV increases effectiveness of hydrogen peroxide
Ethylene oxide	Glass and plastic containers	Cannot be used where chlorides are present or where residual would remain
Heat from CO extrusion process	Plastic containers	No chemicals used
Radiation	Heat-sensitive plastic containers	Can be used to sterilize heat-sensitive packaging materials; expensive; problems with locations radiation source.

The system also utilizes a different sterilizing medium. The rolls are continuously fed into a vertical machine, which sterilizes, forms, fills, and seals the package. Sterilization is accomplished with a combination of hydrogen peroxide and heat. The heat necessary for sterilization may be obtained by a heated stainless-steel drum. Contact with the drum heats the peroxide and effects sterilization. Another system uses packaging material from rolls that are continuously fed into the machine, which forms, fills, and seals the package. The packaging material travels through a bath of hot hydrogen peroxide, which softens the material for forming. Cups are then formed, filled, and sealed with a lid, which also traveled through a hydrogen peroxide bath. Another system utilizes preformed cups to which a lid foil is heat sealed after filling. The cups are fed into the machine where they are sterilized by the peroxide spray followed by heating. The lid material is sterilized by being passed through a peroxide bath. All filling and sealing is done in a chamber that is kept sterile by maintaining a positive pressure with filtered sterilized air. Another system that utilizes preformed cartons, sprays the inside of the carton with low concentrations of hydrogen peroxide. This sprayed carton then passes under a UV light source, which acts synergistically with hydrogen peroxide in destroying microorganisms. Results of tests, using suspension of microorganisms, have shown this combination to be very effective.

24.5.4.1.4 System Utilizing Heat of Extrusion Process for Sterilization

This is a form, fill, seal packaging system and relies on the temperature reached by thermoplastic resin, during the co-extrusion process used to produce multilayer packaging material, to produce a sterile product surface. During production, the multilayer package material is fed into the machine where it is delaminated under sterile conditions. This removes a layer of material and exposes the sterile product's contact surface. The container material is then thermoformed into cups. The lid material, which is also delaminated, is then sealed onto the cup after filling. The sterility of the forming, filling, and sealing areas is maintained by sterile air under positive pressure.

24.5.4.2 Aseptic Filling and Packaging Machines

Aseptic filling and packaging systems can be classified into categories based on the type of packaging material and the method of forming the container (Table 24.4) [85].

24.5.4.2.1 Form/Fill/Seal Machine for Pouches

Figure 24.8 shows the principle of operation of an aseptic vertical form/fill/seal machine for three-sided sealed pouches [86]. The packaging material from a reel, usually a complex multilayer material, is sterilized by hydrogen peroxide in a heated bath, which is the siphon lock to a sterile chamber with a slight overpressure of sterile air. In this chamber, the film is dried, folded over a shoulder to form a tube, and sealed at the long seam. Then the tube, which is closed at the bottom by the cross seal, may be drawn to the nonsterile exterior of the chamber through a tightly fitting flexible lock. Sterile filling inside the chamber is performed using sine filler. In the tube, the contents are protected by a neutral atmosphere of sterile nitrogen, which maintains a very low oxygen concentration in the headspace of the packs. Grippers spread the sealing zones, and vertically reciprocating sealing bars with cutting knifes outside the sterile cabinet transport down, seal, and cut off the pouches. The pack output is 15–35 pouches/min, depending on the size. Products that are, at present, filled by these machines include various tomato products, sauces such as cheese sauce and pizza sauce with particulate. Meal constituents and curries could also be filled [87]. The filling system has CIP and SIP characteristics. Presterilization of the filling system with pressurized steam and of the sterile chamber of the machine by condensed hydrogen peroxide vapors, and also heated air, is performed automatically.

24.5.4.2.2 Thermoform/Fill/Seal Machine for Cups and Trays

Films for both the cups and trays and the lid are drawn from rolls and are transported into the totally closed sterile cabinet through a heated hydrogen peroxide bath. The lower film is heated locally, thermoformed with plug assistance by pressurized sterile air, and the formed packs are then filled. Filling is performed by a special piston filler with reciprocating valves having cutting edges. This filler is able to deposit mixtures with particulate of a few millimeters in size. Shafts of the sliding valves and pistons

TABLE 24.4

Classification of Aseptic Filling and Packaging Systems

Category	Examples of Systems
I. Metal and rigid containers sterilized by heat	
A. Steam/metal containers	Dole hot-air system Drum fillers, e.g., Scholle, FranRica
B. Hot air/composite can	Dole canning systems
II. Webfred paperboard sterilized by hydrogen peroxide	Tetra Pak (BrikPak) International Paper
III. Preformed paperboard containers	Combibloc Liquipak
IV. Preformed, rigid/plastic containers	Metalbox Freshfill Gasti Crosscheck
V. Thermoform–fill–seal	Benco Asepack Bosch Servac Connoffast Thermoforming USA
VI. Flexible plastic containers	
A. Bag-in-box type	Scholle Liquibox
B. Pouches	Asepack Prepac Prodopak Inpaco Bottlepack
C. Blow molded	Serac ALP

penetrate the vessel of the product that has to be filled. At the mechanical drive, external nonsterile air is separated from the sterile air above the product by rolling diaphragms. After filling, the lid is applied to the filled web and sealed at the rims. Headspace gas flushing may be performed. The webs are transported to the nonsterile outside through a contour lock without risk of infection, where the final sealing of the packs, notching, and cutting is carried out [87].

24.5.4.2.3 Filling and Closing Line for Bottles and Jars

The containers, which are precleaned and heated by a special rinser, enter the sterilizing machine in one lane and they are sterilized in several lanes upside down, by treating the inside and the outside with hydrogen peroxide vapors and then drying with sterile air. The containers are inverted and then transported intermittently to the piston filler. In the next stage, the containers are closed with metal caps, which were sterilized with pressurized steam when entering the machine. For liquid products, magnetic-inductive metering devices are used for filling. For plastic bottles heat-seal closures from foil are applied [87].

24.5.4.2.4 The Tetra Pak System

The principle of this system is to take the packaging material directly from the reel and to form it continuously into a tube. The tube is sealed below before filling and above after filling. The main advantage of this pack is that there is no headspace in the finished pack. The precreased web of packaging material unwinds over rollers, which soften the transverse crease. The web is immersed in hydrogen peroxide bath for sterilization. The packaging material is a lamination made of pare, foil, and polyethylene. This combination gives it lightness and a gas barrier, strength and heat-sealing properties [21,78].

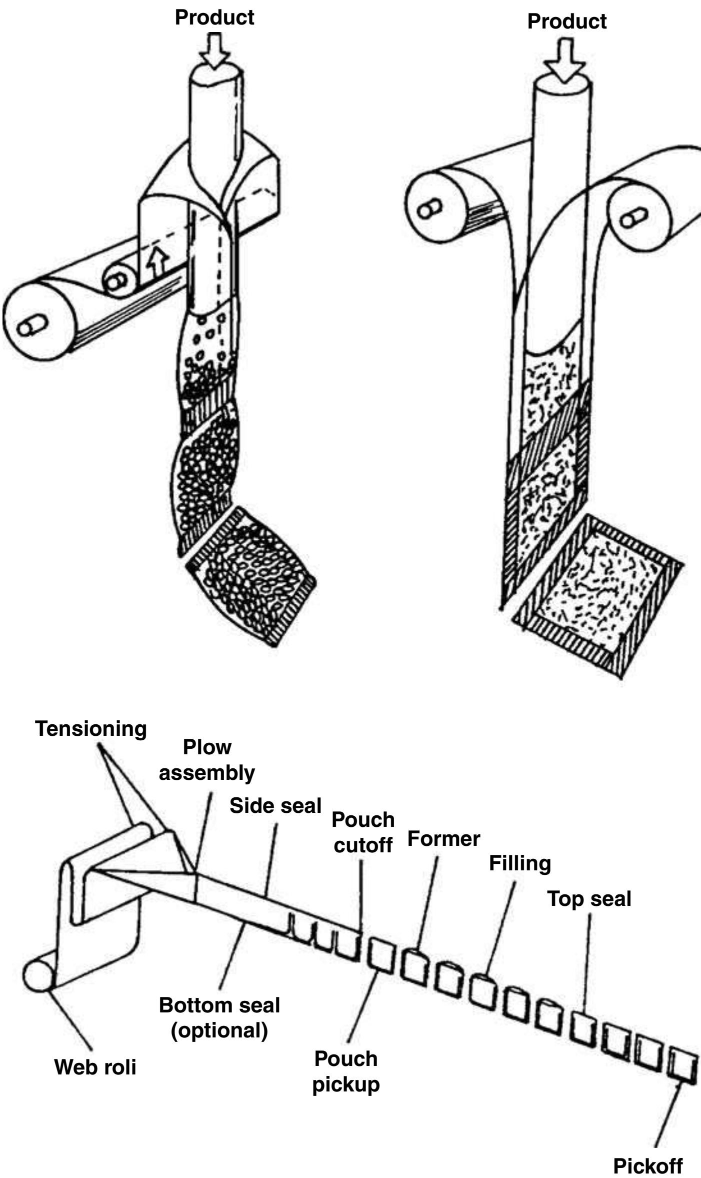

FIGURE 24.8 Form/fill/seal machines. (From Potter, N.N. and Hotchkirs, J.H., *Food Science*, 5th edn., Potter, H.H. and Hotchkirs, J.H., eds., Chapman & Hall, New York, 1995, p. 487, 491.)

24.5.4.2.5 Conoffast System–Continental Can Co.

The system employs prefabricated, sealed pouches that may be internally sterilized by any one of the four methods. Empty pouches are fed through an ultraviolet chamber to minimize external pouch contamination and then filled using hypodermic needles in a superheated steam atmosphere. The needle is withdrawn and the puncture area is heat sealed. Ionizing radiation has been suggested to sterilize the pouch material surfaces. Steam-pressure sterilization restricts the packaging materials to those, which can resist the temperatures. To sterilize the filling and sealing area, and the needle, superheated steam at 145°C can be used [21,78]. The Conoffast system also utilizes the basic package forming–filling– sealing system. Sterilization -of the inside of the package in this system is based on the high temperatures generated within the thermoplastic resins during the extrusion process used to produce the multilaminated packaging material. During the aseptic packaging operation, the top plastic sheet is delaminated, exposing a sterile surface of the packaging material to the food in a sterile environment within the Conoffast unit. Before filling, the packaging material is thermoformed into cup-shaped containers. Sterile food product is filled into the package under sterile conditions. Then the packages are sealed with packaging material from which one layer has been delaminated, again exposing a sterile surface in contact with the food. Sterility during the forming, filling, and sealing operations is maintained by performing these operations in a sterile environment under positive pressure.

24.5.4.2.6 The Combibloc System

In this system, preformed carton blanks are used, which are die cut, creased, side seamed, and printed at the factory origin. This facilitates a more perfect flame-welded seam, thus ensuring good integrity of the seal and the packaging machinery can handle different sizes with a simple height adjustment. A carton blank is drawn from the magazine by suction pads and placed on a mandrel. The sealing surface at the bottom of the carton is softened by hot air. The bottom is folded, pressed, and sealed against the end face of the mandrel. The top is prefolded and then passed on to the aseptic zone where it is sterilized by a hydrogen peroxide spray. After filling, the package top is folded and sealed by ultrasonic welding [78].

24.5.4.2.7 The International Paper System

In this system, the packaging material is taken from a reel. From the reel, the web passes through a series of scoring rollers into a hydrogen peroxide bath for sterilization. The horizontal seals are made by alternating jaws and an induction heater. Individual packages move to the final folding and sealing station for sealing of the top and bottom flaps [78].

24.5.4.2.8 The Gasti System

This system operates with preformed cups made of plastic or aluminum. This facilitates greater flexibility to the operation and allows container quality to be approved in advance. In operation, preformed cups are dispensed from a magazine and are sterilized using hydrogen peroxide vapor. The cups are then filled in the sterile section and are sealed with presterilized lids [78].

24.5.4.2.9 The Liqui-Pak System

This system uses a combination of two sterilizing methods to obtain aseptic packages, viz. hydrogen peroxide and ultraviolet light. This approach has a synergistic effect, which results in a more effective bactericidal action than high concentrations of hydrogen peroxide and ultraviolet light used individually. The cartons travel through the sterile area against a flow of filtered air. The filler is unique with plastic bellows mechanism for sterile dispensing of the product. After filling, the gable carton is heat sealed in a conventional manner [78].

24.5.4.2.10 The Metal Box "FreshFill" System

This system uses preformed cups sterilized by hydrogen peroxide. The product is filled by a multihead filler, with the filling chamber isolated from other machine areas by sterile air overpressure generated by an ultrafilter. The filled cups are sealed using a presterilized foil material and stamped out in the conventional manner. Before start up, the filling chamber, fillers, and supply line are sterilized with steam at 130°C for 20 min [78].

24.5.4.2.11 Avoset System

This system packs fluid products in glass and cans and then in aerosol containers. The system sterilizes containers and product separately and brings them together in a sterile environment. The entire equipment is placed in a controlled environment and all critical elements are sterilized. An operator is present to monitor the equipment. Although sterility is assured, distribution under refrigeration to retard biochemical changes is generally recommended [21,78,88].

24.5.4.2.12 Manton-Gaulin (Pet Inc.)

The system is a glove box. Polyethylene bags are sterilized in the glove box with an ethylene oxide mixture and are heated to 49°C for 6 h. After sterilization, the gas is replaced by sterile air. Sterile mix is aseptically pumped to the filing nozzle within the glove box. Using glove box techniques, the operator fills one bag at a time through the rigid spout. The spout is heat sealed with a laminated foil material. The filled bag leaves the glove box through a chlorinated water trap and is dried outside of the aseptic filling area [21,78]. Scholle container with a semiautomatic aseptic system for filling 6 gallon polyethylene bags has been used. Sterile conditions are maintained by pressurized sterilized air and a continuous spray mist of chlorine solution over a hinged-cap fitment on the bag during filling.

24.5.5 Quality of Aseptically Processed Foods

The basic consideration for sterilizing at high temperatures for a short time is that each 10°C (18°F) increment in sterilization required for destruction of bacteria is reduced by a factor of 10, while the rate of destruction of nutrients and of other chemical reactions affecting product color and flavor decreased by a factor of approximately 3. This is called the z value. Higher is the sterilization temperature, larger is the difference between rates of destruction of reactions. This is the concept upon which the most important advantages of aseptic processing and packaging systems are based. Because of this, the organoleptic and nutritive characteristics of the products processed by aseptic processing systems are retained as compared to that processed by other systems, such as conventional canning [89]. Chemical and flavor changes during high-temperature heating are particularly severe in low-acid foods, which require more severe heat treatment to be sterile. At higher processing temperatures, bacterial spore destruction is much faster than the destruction of food constituents. Foods processed by aseptic processing are better in color and higher in thiamin than those made by conventional canning process. The aseptic processing is used commercially in the dairy industry and to fill fruit juices and purees, pea soups, sauces, and tomato paste.

The effect of HTST sterilization on the nutritive value of meat products has been a subject of great interest. Protein quality may be degraded by the destruction of one or more of the essential amino acids, formation of inter- and intramolecular bonds resistant to digestive enzymes, and alteration in the rate at which the various amino acids are released from protein. This results in a mixture of amino acids that may be less efficient for metabolism and assimilation. The essential amino acids tryptophan, methionine, and lysine are also destroyed by HTST sterilization. Destruction of methionine and accumulation of sulfur dioxide are the main chemical indices of the effect of cooking meat proteins at 120°C–150°C. Protein denaturation is not the only change that occurs during heat processing. Hydrolysis of proteins and polypeptides also takes place. Collagen, eastin, and reticulin compose the connective tissue of meat and are insoluble in water and salt solutions. Collagen is transformed by heating into soluble gelatin. In this conversion, some of the cross links are broken, resulting in shortening and disorganization of the protein chains. The conversion also accounts for higher protein solubility in the processed meat products. The aseptic strained meat has been shown to be more nutritious and higher in thiamin retention. Aseptically processed meat and vegetable products lose thiamin and pyridoxine but other vitamins are largely unaffected. There are negligible vitamin losses in aseptically processed milk and lipids, carbohydrates, and minerals are virtually unaffected. Riboflavin, thiamin, pantothenic acid, biotin, nicotinic acid, and vitamins B6 and B12 are unaffected. Nutrient losses also occur during periods of prolonged storage, and these should be considered when assessing the importance of sterilized foods in the diet.

24.5.6 Nutritional Aspects of Aseptically Processed Foods

The use of HTST processes is particularly adaptable to aseptic processing. The destruction of nutrients during the thermal processing is dependent on (1) time–temperature treatment used as the basis of the process, and (2) the rate of heat transfer into the product. In an aseptic processing system, as the processing temperature is about 150°C for a very short period, the nutrient retention is greatly enhanced. The effects of heat treatments of equal microbial lethality on selected food constituents, including nutrients, color, proteins, and flavor compounds, have been reported [90]. The retention of vitamin C in tomato juice improves during HTST processing. For natural products containing enzymes, the limitation of the benefits of HTST processing occurs when the basis of the process shifts from microbes to enzymes at a temperature of 130°C–145°C for shorter periods.

In an evaluation of HTST aseptic processing [91], it was found that thiamin retention was significantly greater in HTST products than conventionally canned and retorted products. For pyridoxine, the benefit of HTST was not as evident, as destruction of pyridoxine is not much temperature-dependent as that of thiamin. HTST aseptic processing also results in the significant improvements in organoleptic qualities [92]. Most of the reports on the effect of thermal processing on nutrients only contain information on the content of a specific nutrient after the thermal process and give the percentage retention or loss of the nutrient. As there are numerous processing methods and the time–temperature possibilities for accomplishing commercial sterilization, it is improper to assume that the nutrient losses reported in the literature represent the average or normal for the industry. Hence, the data on such nutrient losses are of limited value but can be used as a guideline for selecting an optimum process schedule [92]. Nutrient losses range from 0% to 90%, depending on the nutrient and the product. These losses represent the sum of the losses during the entire processing including blanching. In some of the studies [93–95], the temperature for sterilization of foods has been optimized to maximize retention of nutrients or minimize the production of an undesirable product.

24.5.7 Packaging of Aseptically Processed Foods

24.5.7.1 Introduction

Packaging of aseptically processed food is the most critical key for a successful operation. The product has to be packaged in the form desired, which will yield the benefits anticipated after the product has been sterilized. This includes process design, process equipment, formulation, and raw material quality. Besides, the machinery used, the materials used for the container, and the closure and the sterilants that can be used with these materials are important. The aseptic packaging system must be capable of filling the product produced by the UHT or HTST system in an aseptic manner and sealing the container hermetically so that sterility is maintained throughout the handling and distribution process. Thus, the system must be capable of (a) being connected to the processing system in a manner that enables aseptic transfer of product to take place, (b) being effectively sterilized before use, (c) carrying out the filling, sealing, and critical transfer operations in a “sterile” environment, and (d) being cleaned properly after use. The packages in use vary from traditional tin-plate can and glass bottle to the nonrigid and semirigid containers based on thermoplastics or combinations of thermoplastics with paperboard and metal. The type of container used will be influenced by the nature of the contents, cost, and its acceptability to the consumer. The relatively low cost and wide acceptance by the consumer are the main reasons for the recent proliferation in the use of the carton-type packs for fruit juice, juice-based beverages, and dairy products. In addition to systems producing packages intended for sale directly to the public, bulk packaging installations are used for conserving raw materials or intermediates intended for reprocessing or for use in catering establishments.

Many systems have been proposed for the aseptic packaging of food, but some authorities consider that not all those proposed meet the criteria for full asepsis. Thus, they should be more accurately described as ultraclean fill machines and used as means of extending the shelf life of products distributed through the cold chain. Some systems, by their nature, restrict the packaging material to simple monolayer plastics, and many foods packaged in these materials have a limited shelf life due to their poor oxygen barrier characteristics. Others are able to employ multilayered barrier plastics or include aluminum foil as a component, and in such cases shelf life is much improved. Containers made from glass or metal of adequate thickness may be considered impermeable [78]. The method of sterilizing the package, or the material from which it is formed, is important in retaining the characteristics of the packaging material. Sterilizing processes may alter the characteristics of the package, or material, and render it undesirable for packaging the food product. Obviously, the material must perform and produce the results desired. Some of the factors that should be considered include [96]: (i) performance with the food (gas transmission, water transmission, absorbance—packaged product flavors, odors, colors, and vitamins being absorbed by the container material, adsorbance—a few molecules being extracted from the package material and being held by the product, combinations of absorbency and adsorbancy, chemical inertness to the food, or desirable reactions with the food, sterilization, wet ability, temperature limitations, and inertness to the sterilizing agents, can be laminated or special surfaces applied, material handling characteristics (empty)), (ii) cost, and (iii) form and mechanical characteristics (if it can be molded, size limitations, shape limitations, easy opening/closures available, tamper-proof closures or tamper-evident systems available, configuration after storage, material handling characteristics and suitability for use with conveyors, labelers, casers, and over cappers), (iv) shipping and handling (toughness or strength, type of over wrap or cases required, fillers between packages in the cases required) and (v) comply with regulations (food safety FDA, FSIS, 3A, and PMO).

The materials that are used for aseptic packages are practically infinite. This is because the use of laminated materials, using plastics as well as metals, and the development of new plastic materials and alloys, is occurring regularly. There are also variations within a defined product, so it may vary from different manufacturers, even though generically it is the same. For example, paper from one supplier may vary from paper that comes from another vendor. The same is true for metals such as steels and aluminum, plastics, and laminates. These variations can cause the product to change over a short or long period. Some of the common materials used for aseptic packages include the following [96]: (i) stainless steel (bins, tanks, and rail cars), (ii) carbon steel (cans and closures), (iii) aluminum (cans and closures), and (iv) plastics (cups and square/rectangular packages) (acetal, nylons [66 or others], polypropylene, polyester, polycarbonate, acrylic, ABS—acrylonitrile-butadiene-styrene, PVC—polyvinyl chloride, polystyrene, high-density polyethylene, low-density polypropylene, EVAL—ethyl vinyl acetate, EVOH—ethyl vinyl alcohol, PVDC—polyvinylidene chloride, paper, paper-based laminates, and plastic-based laminates).

It should be considered that new materials are constantly being proposed for approval by the FDA for aseptic packages with specified types of sterilants. Also, certain laminates that exist today are being made in a single polymer form; hence, a resin may contain three or four different polymers that have combined properties. The reason for manufacturing laminates out of various materials is to build into the packaging material(s), those properties that are most critical for the food product over a period of time (which may be short, medium, or long); and it will be either inert to the product or react with it in a favorable way, such as tin cans reacting with citrus juices. The problem of the food product compatibility with container materials over a period of time should be briefly addressed. This is an area that has not received the attention it should have from packaging manufacturers or food processors.

Materials can absorb desirable components from the food, thereby causing the food to have less flavor, color, odor, and nutrients. Another condition that exists is that the packaging materials can actually have certain molecules stripped from it, thereby changing the food product's color, flavor, odor, and vitamin content. Also, there are combinations of the two where the material used for package is reacting with the food to change its properties, and in turn the food is reacting with the packaging material and losing some of its desirable characteristics. This situation is never ending and may actually accelerate as color changes occur [96].

24.5.7.2 Aseptic Packaging

In general, aseptic packaging is coupled with HTST/ UHT methods of food sterilization, and the two processes are joined in a complete integrated system to produce aseptically processed foods.

24.5.7.2.1 Drums

The drum is placed under the filling chamber and then raised up to seal against a gasket. Saturated steam is introduced into the drum and the interior of the drum is pressurized with steam. After a total 2.5-min cycle, a filling tube lowers into the drum and dispenses sterile product to fill the drum. The filling tube retracts and a sealing head with magnetically attached lid swings over the drum. Steam pressure is employed to apply pressure to crimping jaws to fix the gasketed lid into place. Alternatively, an empty drum and cover are placed in a filling retort, and both are steam sterilized under pressure. The sterile product is then filled into the drum, and the lid is placed. The drum is removed, and another cycle is initiated. The capacity of the system with two filling retorts is 24 drums per hour [21,97]. The advantage claimed of the drum system is lowered shipping weight because one large reusable container is used rather than 75 numbers of No. 10 cans plus 12–13 corrugated cases. Product recovery is higher because there is far less surface area to drain. Further, the labor cost of emptying one 200 L container is significantly less than the cost of opening 75 cans.

24.5.7.2.2 Tanks

Instead of pulping, finishing, and concentrating into paste for bulk handling, tomatoes are simply chopped, sterilized, and filled aseptically into 380 L (100 gallon) tanks. Tomatoes are washed, chopped into chunks, heated in tubular heaters, cooled, deaerated, and subsequently filled into tanks under a nitrogen blanket. Storage tanks are galvanized steel, lined with a baked-on epoxy coating. Tanks are chemically sterilized before filling [21]. The basic objective is to provide tomato processors with a large source of raw material that can be converted into many different products over a long period. Among the products that can be made from chopped tomatoes are paste, puree, sauce, catsup, pizza sauce, juice, and chili sauce.

24.5.7.2.3 Glass Containers

Aseptic packaging in glass containers has not been broadly successful on a commercial basis. Juice is heated to 93°C and held for 9 s and cooled to 20°C in a heat exchanger 1 and 2 L bottles are cleaned by rinsing with water. After washing, the bottles are discharged into a closed area blanketed with 99.9% sterile, dehumidified air. The filler is sterilized with boiling water prior to the operation. Closures are steam sterilized and taken into the clean room. Sterile juice is filled into the "sterilized jars" and capped in the clean area. The product, known as aseptic cold-pack juice, is reported to have long shelf life under 10°C [21]. At room temperature storage, hot-filled (conventional) juice has an acceptable shelf life of 1 month as compared to 3 months for cold-filled juice. The basic problem with glass is that the maximum temperature differential glass containers can withstand is approximately 15°C. Thermal shock between inner and outer surfaces leads to unequal thermal expansion sufficient to crack the glass.

24.5.7.2.4 Plastic Containers

The concept of aseptic packaging holds that presterilized product is filled under aseptic conditions into a presterilized container. As long as the container can exclude microorganisms and prevent passage of gas, container material need not be rigid. Both Metal in heavy gages and glass are fabricated into rigid containers.No rigid plastics are employed commercially for sterile packaging. All plastic materials are partially permeable to moisture and gas. Because of implied low-strength characteristics, food products that have been sterilized are packaged in semirigid materials. Paperboard with appropriate coatings is also utilized to form semirigid packages [21]. Two basic types of semirigid systems are in commercial use [21]: (i) thermoform, fill, and seal, and (ii) preformed cups, fill, and seal.

24.5.7.2.5 Flexible Packages

The Tetra Pak AB system is often considered as a flexible packaging system. Technically, it is not a flexible packaging system because it is made of paperboard rather than a true flexible material. The polyethylene pouching material is sterilized using a hydrogen peroxide bath. The vertical form, fill, and seal milk pouching equipment is converted for aseptic packaging [98].

24.5.7.2.6 Reclosable Aseptic Packaging System

Reclosing is useful for products such as milk, fruit juice, and wine. Shaking is important for products such as pulpy fruit juices. The system consists of a closure with two parts. The visible part is a rectangular polypropene chassis with a cap that snaps open and shut on a hinge. The device is glued to the top corner surface of the pack with hot-melt adhesive [99]. Underneath the cap is the second part of the system—an aluminum pull tab that covers the pouring hole and provides good tamper evidence. The pull tab, which is wielded to the inner liner of the package, is easy to peel off. It reveals a long, pear-shaped hole that has excellent pouring characteristics. The reclosing system is extremely sanitary, unlike "punch"-style cap devices that require users to poke a finger into the product to open the package. High-quality long-life product is achieved by the aseptic filling process. This package provides easy stackability, is space saving in terms of transportation (both filled and unfilled cartons), has low weight, saves cost in carton material production, and has high level of environmental friendliness. The reclosable system increases the intrinsic value of the carton and provides the consumer with easy opening, spill-free pouring, and reliable reclosure as well as hygienic handling. After reclosure, the product is protected and can be shaken as necessary. The product quality remains unimpaired and protected from foreign flavors. The carton with the system fitted is ideal for refrigerator storage. The new carton image is completed by the slim, elegant shape, suggestive of high quality.

24.5.8 Energy Aspects of Aseptic Processing

The energy aspects of aseptic processing have been widely carried out on milk and most of the data available are on milk products. Energy requirement of aseptic processing units containing steam injection without regeneration, tube heat exchanger, as applied to the processing of milk, has been evaluated. For steam infusion, the system consumed about 1000 kJ/kg of milk [100]. For tube heat exchanger, the system consumed about 400 kJ/kg milk [101]. The total energy requirement in the HTST system for milk processing was about 225 kJ/kg of milk. The break-up of the energy was 98 kJ/kg milk thermal, 30 kJ/kg electrical, and 97 kJ/kg refrigeration. The steam infusion system requires about 360 kJ/kg of milk as it is a direct contact heating and is more compared to indirect heating like tube heat exchanger [102]. Cooling below 30°C is not required for aseptic processed milk. This saves more energy and is about 100 kJ/kg of milk. In addition, aseptic processing of products does not require postprocessing refrigeration resulting in further savings of 900 kJ/kg of product [102]. The most widely used heat exchangers in aseptic processing of foods are the plate and tubular type. If direct heating and cooling of product to sterilizing temperatures is used, the energy consumed is considerable. Therefore, use of regeneration of heat is important [103]. The plate heat exchanger holds a distinct edge in this regard; regeneration efficiencies of 90% (direct) or 85% (indirect) have been used. Tubular units can achieve regeneration by indirect methods, whereby a secondary water flow exchanges heat from the preheater tubes to the cooler tubes. Indirect regeneration requires four times the surface as does direct, for the same heat recovery. As a result, regeneration efficiencies over 70% are rare. Steam injection/infusion systems are not efficient: for example, with milk duties regeneration accounts for only slightly more than 50% of the total heat input. Regeneration with swept surface units, though possible, is not used due to capital cost consideration.

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