Food processing was practiced from the prehistoric age mainly to fulfill the requirements of military and sailing persons. The major food processing techniques followed include drying, salting and drying, fermenting, and smoking until the advent of heat-processed products in glass containers by Nicolas Appert. Preservation aims to process foods for storing for longer duration. Human beings are dependent on products of plant and animal origin for food. As most of these products are readily available only during certain seasons of the year and fresh food spoils quickly, methods have been developed to preserve foods. Preservation must be seen as a way of storing excess foods that are abundantly available at certain times of the year, so that they can be consumed in times
when food is scarce. Apart from preserving for a longer duration, processing also helps in converting raw foods into edible and palatable form, increases organoleptic quality, makes foods safe for consumption, helps in bringing nutritional and food security, increases product diversification, minimizes wastage, generates employment, and helps in earning foreign exchange by exporting processed food products.

Fish and shellfishes pass through a number of processes immediately after catch before it is consumed or sold for consumption. These processes can be divided into primary processing and secondary processing. Primary processing includes the steps that enable fish to be stored or sold for further processing, packaging, and distribution. Examples include washing, cleaning, heading, gilling, scaling, gutting, grading, filleting, deboning, skinning, chilling, and freezing. Whereas secondary processing includes the production of "value-added products." Examples are salting, drying, smoking, marinating, and packaging ready-to-eat foods. Fresh fish spoils very quickly due to various internal and external factors. Once the fish has been caught, spoilage progresses rapidly. In the high ambient temperatures of the tropics, fish will spoil within 12 h. By adopting good fishing techniques (to minimize fish damage) and cooling the fish immediately, the storage life can be increased. It is well established that spoilage of fish and shellfish is mainly due to three destructive processes. These are

1. Enzymatic decomposition
2. Bacterial action
3. Oxidation process

3.1 ENZYMATIC DECOMPOSITION

Enzymes are powerful biological chemicals that occur in the tissue of all living organisms. They perform important functions, either by breaking down large food compounds into smaller ones in the stomach and gut, as in digestion, or by helping to make new compounds for building new body tissue or for producing energy. In the living animal, the body keeps a close control on the activity of enzymes. However, when the animal dies this control is lost. The enzymes will start attacking the flesh of the body, breaking down compounds to smaller ones, just like the process of digestion (autolysis). Enzyme activity depends on various factors like temperature, pH, and water activity.

3.2 BACTERIAL ACTION

Bacteria or germs are living organisms that are found everywhere in nature. They are classified mainly as psychrophile, mesophile, and thermophile bacteria. Psychrophilic or psychrotrophic bacteria are microorganisms with optimum growth temperatures in the region of 10°C–15°C and 20°C, respectively, capable of growth down to 0°C. The bacteria growing on fish spoiling in ice are predominately psychrophilic. Mesophiles have an optimum growth temperature, the temperature at which they multiply most rapidly, in the region of 35°C–40°C. Food poisoning organisms are adapted to grow in the body of warm-blooded animals and are mesophiles, though some can grow at chilled temperatures. Thermophilic bacteria grow best at elevated temperatures in the range of 55°C–75°C. *Bacillus stearothermophilus* is an extremely heat-resistant thermophilic spore-forming bacteria, which has been found to be responsible for the flat-sour spoilage of canned foods. Although there are many useful bacteria, they pose problems in the handling of food either by spoiling the food or by causing food poisoning. Fish carry millions of bacteria on their external surfaces (skin and gills) and in their intestines. A healthy, living fish uses its natural defense mechanism to protect it against the harmful effects of bacteria. However, when a fish dies, the defense mechanism stops working. This allows the bacteria the opportunity to feed on the flesh, multiply, and eventually spoil the fish. Conditions which allow bacteria to multiply are suitable
temperatures, the presence of water, and a source of food. Bacteria will enter the flesh easily if the fish has been damaged through improper handling and storage.

### 3.3 OXIDATION

Rancidity is a more widely used term for oxidation. It occurs when oxygen in the air reacts with oil or fat in the flesh of the fish. This leads to a sour or stale, unpleasant smell or taste. Fatty pelagic fishes like skipjack, seer, mackerel, herring, scads, and sardines store fat in their flesh and can turn rancid quickly if not handled and stored properly. White-fleshed demersal fish store fat in their livers, so these must be removed during gutting. Frozen-stored fatty fish can spoil through oxidation if stored improperly, even though the temperature is too low for bacteria to grow or enzymes to work effectively.

### 3.4 MINIMIZING FISH SPOILAGE

Fish spoilage can be effectively minimized if the effects of enzymes, bacteria, and oxidation are controlled properly. This can be achieved by understanding the optimum conditions that enzymes, bacteria, and oxidation processes prefer and modifying these conditions which helps to preserve food. Many processing procedures aim to alter these conditions to achieve preservation. Some of the approaches are given in Table 3.1.

#### 3.4.1 LOWERING THE TEMPERATURE

Chilling food in the refrigerator or with ice slows down the destructive processes of enzymes and bacteria. The shelf life of food can therefore be extended by many days. If the temperature is lowered further, as in freezing, much longer storage times are possible because all bacterial activity and virtually all enzymatic action is stopped if the temperature is maintained properly.

#### 3.4.2 RAISING THE TEMPERATURE

High temperatures kill bacteria and destroy enzymes. Processes such as cooking (boiling, frying, and baking), hot smoking, canning, and pasteurization extend the keeping time of the food.

#### 3.4.3 DRYING OR DEHYDRATION

Removing water from the food by drying is a very old and effective method of controlling bacterial and enzymatic spoilage of food. Drying can be achieved under the sun and wind (natural drying) or

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in a mechanical drier. Salting helps the drying process too, as it binds the water, making it unavailable to bacteria. Some high-temperature processing such as hot smoking uses a combination of drying and high temperatures to control bacteria and enzymes.

Oxidation problems of fatty fish can be controlled by preventing the contact of oxygen to the product. This is achieved by packing the fish in high barrier plastic bags or by packing under vacuum or packing with oxygen absorbing sachet.

The food preservation methods are aimed at preventing undesirable changes in the wholesomeness, nutritive value, and sensory quality of food by controlling the growth of microorganisms and obviating contamination by adopting economic methods. Thermal processing is one such method, by which food is given sufficient heat treatment in a hermetically sealed container to destroy pathogenic and/or spoilage causing microorganisms and their spores, antinutrients, and enzymes that cause degradation in the food.

An Italian naturalist Spallanzani concluded from his experiments that organisms causing spoilage in a number of food products were carried in the air, and by heating the contaminated infusions in airtight container, the development of the organism was prevented. Although Spallanzani’s work was the key to the preservation of food by heat, little use appears to have been made of it until the early part of the nineteenth century when Nicholas Appert first succeeded in preserving food in airtight glass containers. So, the Frenchman Nicholas Appert is credited as the inventor of this noble technology.

3.5 THERMAL PROCESSING

Thermal processing of foods constitutes a significant part of the world’s food preservation technique. Thermally processed foods include heat-processed foods in bottles, jars, metal cans, pouches, tubes, and plastic-coated cartons. The heat treatment is applied with the objective of destroying specific, usually pathogenic organisms and also spoilage causing microorganisms. The first publisher on canning of food was French confectioner Nicholas Appert, who in 1810 edited “L’art de conserver pendant plusieurs années toutes les substances animales et végétales,” which was later translated to English “Of preserving all kinds of animal and vegetable substances for several years.”

Demand for better quality processed food is increasing as civilization developed. This led to the development of a large food preservation industry, aiming to supply food that is sterile, nutritious, and economical. Thermal sterilization of foods is the most significant part of this industry and is one of the most effective means of preserving our food supply (Karel et al., 1975). The objective of sterilization is to extend the shelf life of food products and make them safe for human consumption by destroying the pathogenic microorganisms.

Thermal processing is the most common sterilization method, which employs steam as the heating medium, although other types of heating medium like steam-air mixture, pressurized hot water, and direct flame are available. Saturated steam is the most commonly and highly desirable heating medium used for commercial sterilization of canned foods. Other methods of sterilization such as pulsed electric field (Barbosa-Canovas et al., 1998, 2001), ultrahigh hydrostatic pressure (Barbosa-Canovas et al., 1998; Palou et al., 1999; Furukawa and Hayakawa, 2000), and ultraviolet treatment (Farid et al., 2000) have been widely studied. However, these methods fail to replace the common thermal processing mainly due to their inability to inactivate enzymes, which can cause various negative effects such as discoloration, bitter flavor, and softening (Clark, 2002).

3.5.1 PRINCIPLES OF THERMAL PROCESSING

Thermal processing which is also commonly referred as heat processing or canning is a means of achieving long-term microbiological stability for non-dried foods without the use of refrigeration, by prolonged heating in hermetically sealed containers, such as cans or retortable pouches, to render the contents of the container sterile. The concept of thermal processing has come a long way
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since Nicholas Appert’s time. Later, Bigelow and Ball developed the scientific basis for calculating the sterilization process for producing safe foods. Today, thermal processing forms one of the most widely used methods of preserving and extending the shelf life of food products including seafoods. Thermal processing involves the application of high-temperature treatment for sufficient time to destroy all the microorganisms of public health and spoilage concerns. The important factors to be considered in thermal processing are the seal integrity, sufficient process lethality, and post-process hygiene. The seal integrity is achieved by a hermetic seal, which helps in preventing recontamination and creates an environment inside the container that prevents the growth of other microorganisms of higher heat resistance. It also helps in preventing toxin production from pathogens. The time-temperature schedule for the required process lethality should be effective to eliminate the most perilous and heat-resistant mesophilic anaerobic spore-forming pathogen *Clostridium botulinum*. Post-process hygiene is of utmost importance for heat-processed foods as the heat-processed containers, which are still warm and wet, may lead to inward leakage through the seal. Hence, the use of chlorinated water is mandatory for can washing and cooling.

Normally, thermal processing is not designed to destroy all microorganisms in a packaged product. Such a process may destroy all the important nutrients and results in low product quality. Instead of this, the pathogenic microorganisms in a hermetically sealed container are destroyed by heating, and a suitable environment is created inside the container which does not support the growth of spoilage-type microorganisms. Several factors must be considered for deciding the extent of the heat processing (Fellows, 1988). These are

1. Type and heat resistance of the target microorganism, spore, or enzyme present in the food
2. pH of the food
3. Heating conditions
4. Thermo-physical properties of the food and the container shape and size
5. Storage conditions

Food contain different microorganisms and/or enzymes that the thermal process is designed to destroy. In order to determine the type of microorganism on which the process should be based, several factors must be considered. In foods that are vacuum packed in hermetically sealed containers, low oxygen levels are intentionally achieved. Therefore, the prevailing conditions are not conducive to the growth of microorganisms that require oxygen (obligate aerobes) to create food spoilage or public-health problems. Further, the spores of obligate aerobes are less heat resistant than the microbial spores that grow under anaerobic conditions (facultative or obligate anaerobes). The heat resistance of food spoilage microorganisms has been studied extensively, and thermal resistance data are available for the more resistant organisms in a variety of products (Esty and Meyer, 1922). The heat tolerance of microorganisms is greatly influenced by pH or acidity. From a thermal-processing standpoint, foods are divided into three pH groups: high-acid foods (pH < 3.7), acid or medium-acid foods (pH 3.7–4.5), and low-acid foods (pH > 4.5). With reference to thermal processing, the most important distinction in the pH classification is the dividing line between acid and low-acid foods.

Sterilization or its commercial equivalent for the reduction of viable microbes to some predetermined level forms the basis of a substantial class of food preservation operations and is particularly important in canning (Kumar et al., 2001). The main purpose of sterilization is the destruction of microorganisms by heating, which causes spoilage of food during preservation. The usually targeted microorganism in the sterilization of foods is the *C. botulinum*. However, the use of non-pathogenic and more resistant species is preferred, particularly *Clostridium sporogenes* (PA 3679) (Ranganna, 1986). The argument is that once these have been destroyed, all other less heat-resistant spores can be safely assumed to be destroyed.

Most of the research dealing with thermal processing devotes special attention to *C. botulinum*, which is a highly heat-resistant, rod-shaped, spore-forming, anaerobic pathogen that produces an
extremely potent exotoxin under favorable conditions, which leads to “botulism.” It has been generally accepted that \textit{C. botulinum} do not grow and produce toxins below a pH of 4.5 and is a potential health hazard only in foods with a pH above 4.5. Therefore, all low-acid foods should receive a process that is adequate to destroy \textit{C. botulinum}. Generally, canned foods receive a heat treatment that is more severe than that required to destroy \textit{C. botulinum} since several other species of microorganisms have a greater heat resistance. An order-of-the-process factor of 12D is used in the commercial heat processing of low-acid foods that do not contain preservation levels of salt or other bactericidal or bacteriostatic chemicals (Gillespy, 1951).

Thermal processing is designed to destroy different microorganisms and enzymes present in the food. Normally in thermal processing, an exhausting step is carried out before sealing the containers. In some cases, food is vacuum packed in hermetically sealed containers. In such cases very low levels of oxygen is intentionally achieved. Hence, the prevailing conditions are not favorable for the growth of microorganisms that require oxygen (obligate aerobes) to create food spoilage or public-health problems. Further, the spores of obligate aerobes are less heat resistant than the microbial spores that grow under anaerobic conditions (facultative or obligate anaerobes). The growth and activity of these anaerobic microorganisms are largely pH dependent. From a thermal-processing standpoint, foods are divided into three distinct pH groups which are given below. Changes in the intrinsic properties of food, mainly salt, water activity, and pH are known to affect the ability of microorganisms to survive the thermal processes in addition to their genotype. Due to health-related concerns on the use of salt, there is an increased demand to reduce salt levels in foods. The heat tolerance of microorganisms is greatly influenced by pH or acidity. The United States Food and Drug Administration (FDA) has classified foods in the federal register (21 CFR Part 114) as follows:

1. High-acid foods (pH < 3.7; e.g., apple, apple juice, apple cider, apple sauce, berries, cherry (red sour), cranberry juice, cranberry sauce, fruit jellies, grapefruit juice, grapefruit pulp, lemon juice, lime juice, orange juice, pineapple juice, sour pickles, and vinegar)
2. A cid or medium-acid foods (pH 3.7-4.5; e.g., fruit jams, fruit cocktail, grapes, tomato, tomato juice, peaches, pinto, pineapple slices, potato salad, prune juice, and vegetable juice)
3. Low-acid foods (pH > 4.5; e.g., all meats, fish and shellfish, vegetables, mixed entries, and most soups).

The acidity of the substrate or medium in which microorganisms are present is an important factor in determining the degree of heating required. With reference to thermal processing of food products, special attention should be devoted to \textit{C. botulinum} which is a highly heat-resistant, rod-shaped, spore-forming, anaerobic pathogen that produces the \textit{botulism} toxin. It has been generally accepted that \textit{C. botulinum} and other spore-forming human pathogens does not grow and produce toxins below a pH of 4.6. The organisms that can grow in such acid conditions are destroyed by relatively mild heat treatments. Some spore formers may cause spoilage of this category of foods, for example, \textit{Bacillus coagulans}, \textit{Clostridium butyricum}, and \textit{Bacillus licheniformis}, as well as ascospores of \textit{Byssoclamys fulva} and \textit{Byssoclamys nivea}, which are often present in soft fruits such as strawberries. For food with pH values greater than 4.5, so-called low-acid products which include sherry products, it is necessary to apply a time–temperature regime sufficient to inactivate spores of \textit{C. botulinum} which is commonly referred to as a \textit{botulinum cook} in the industry. Thermal processes are calibrated in terms of the equivalent time the thermal center of the product, that is, the point of the product in the container most distant from the heat source or cold spot, spends at 121.1°C, and this thermal process lethality time is termed \(D_0\) value. Although there are other microorganisms, for example, \textit{B. stearothermophilus}, \textit{Bacillus thermoacidurans}, and \textit{Clostridium thermosaccolyticum}, which are thermophilic in nature (optimal growth temperature \(-50^\circ\text{C}\text{ to} -55^\circ\text{C}\)) and are more heat resistant than \textit{C. botulinum}, a compromise is drawn on the practical impossibility of achieving full sterility in the contents of a hermetically sealed container during commercial heat processing, whereby the initial bacterial load is destroyed.
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through sufficient decimal reductions to reduce the possibility of a single organism surviving to an acceptably low level. This level depends on the organism, usually *C. botulinum*, which the process is designed to destroy. The time required to reduce the number of spores of this organism (or any other microorganism) by a factor of 10 at a specific reference temperature (121.1°C) is the decimal reduction time, or the *D* value, denoted by *D*₀. The *D*₀ value for *C. botulinum* spores can be taken as 0.25 min. A reduction by a factor of 10¹², regarded as an acceptably low level, requires 3 min at 121.1°C, and is known as the process value, or *F* value, designated *F*₀, so, in this case, *F*₀ = 3, which is known as a “botulinum cook” which is the basis of commercial sterility.

3.5.2 Thermal Resistance of Microorganisms

For establishing safe thermal processing, knowledge on the target microorganism or enzyme, its thermal resistance, microbiological history of the product, composition of the product, and storage conditions are essential. After identifying the target microorganism, the thermal resistance of the microorganism must be determined under conditions similar to the container. Thermal destruction of microorganism generally follows a first-order reaction indicating a logarithmic order of death, that is, the logarithm of the number of microorganisms surviving a given heat treatment at a particular temperature plotted against the heating time (survivor curve) will give a straight line (Figure 3.1). The microbial destruction rate is generally defined in terms of a decimal reduction time (*D* value) which represents a heating time that results in 90% destruction of the existing microbial population or one decimal reduction in the surviving microbial population. Graphically, this represents the time during which the survival curve passes through one logarithmic cycle (Figure 3.1). Mathematically,

\[ D = \frac{(t_2 - t_1)}{(\log a - \log b)} \]

where *a* and *b* are the survivor counts following heating for *t*_₁ and *t*_₂ min, respectively. As the survivor or destruction curve follows the logarithmic nature, the complete destruction of the

![Figure 3.1 Survivor curve.](#)
microorganisms is theoretically not possible. From the survivor curve, as the graph is known, it can be seen that the time interval required to bring about one decimal reduction, that is, 90% reduction, in the number of survivors is constant. This means that the time to reduce the spore population from 10,000 to 1,000 is the same as the time required to reduce the spore population from 1,000 to 100. This time interval is known as the decimal reduction time or the "D" value.

The D value for bacterial spores is independent of initial numbers, but it is affected by the temperature of the heating medium. The higher the temperature, the faster the rate of thermal destruction and lower the D value. This is why thermal sterilization of canned fishery products relies on pressure cooking at elevated temperatures (>100°C) rather than cooking in steam or water, which is open to the atmosphere. The unit of measurement for D is "minute." An important feature of the survivor curve is that no matter how many decimal reductions in spore numbers are brought about by a thermal process, there will always be some probability of spore survival. So in practice, the fish canners are satisfied if the probability of pathogenic spore survival is sufficiently remote, and the associated public-health risk is also not significant. In addition to this they also accept, as a commercial risk, a slightly higher probability of non-pathogenic spoilage. Different microorganisms and their spores have different D values as shown in Table 3.2.

Since bacterial spores possess different D values, a thermal process designed to reduce spore population of one species by a factor of $10^9$ (i.e., 9 decimal reductions or 9D process) will bring about a different order of destruction for spores of another species. Thermophilic spores are more heat resistant and therefore have higher D values than other mesophilic spores.

### 3.5.3 Thermal Processing Requirements for Canned Fishery Products

Thermal processing is carried out for achieving two objectives; the first is consumer safety from botulism and the second is nonpathogenic spoilage which is deemed commercially acceptable to a certain extent. If heat processing is inadequate, the possibility of spoilage due to *C. botulinum* is more and will endanger the health of the consumer. Safety from botulism is made possible by making the probability of *C. botulinum* spores surviving the heat process sufficiently remote and presents no significant health risk to the consumer. An acceptable low level in the context of this dangerously pathogenic organism means less than one in a billion ($10^{-12}$) chance of survival. Such a low probability of spore survival is commercially acceptable as it does not represent a significant health risk. The excellent safety record of the canning industry with respect to the incidence of botulism through under processing confirms the validity of this judgment. An acceptable low level in the case of thermophilic nonpathogenic organisms should be arrived at judiciously considering the factors like very high D value, risk of flat-sour spoilage, commercial viability, and profitability. Since nonpathogenic organisms do not endanger the health of the consumer, process adequacy...
is generally assessed in terms of the probability of spore survival which is judged commercially acceptable. Considering all these facts, it is generally found acceptable if thermophilic spore levels are reduced to around $10^{-2}$ to $10^{-3}$ per gram. Another reason for this acceptance is that the survivors will not germinate if the storage temperature is kept below the thermophilic optimum growth temperature, that is, below 35°C.

### 3.5.4 Commercial Sterility

If the thermal process is sufficient to fulfill the criteria of safety and prevention of nonpathogenic spoilage under normal conditions of transport and storage, the product is said to be “commercially sterile.” In relation to canned foods, the FAO/WHO Codex Alimentarius Commission defines commercial sterility as the condition achieved by the application of heat, sufficient alone or in combination with other appropriate treatments, to render the food free from microorganisms capable of growing in the food at normal non-refrigerated conditions at which the food is likely to be held during distribution and storage. Apart from this concept, there are circumstances where a canner will select a process which is more severe than that required for commercial sterility as in the case of mackerel and sardine where bone softening is considered desirable.

### 3.5.5 Thermal Process Evaluation

The primary objective of thermal processing of canned foods is to destroy microorganisms capable of causing deterioration of the foods or endangering the health of consumer (Hersom and Hulland, 1980). The basic ideas of thermal process calculation are well presented in several published articles and textbooks (Ball and Olson, 1957; Lopez, 1969; Stumbo, 1973; Hayakawa, 1978; Merson et al., 1978; Ramaswamy et al., 1992; Teixiera, 1992). The first systematic approach to the problem of applying bacteriology and physical data to the determination of thermal process time for canned foods was that of Bigelow et al. (1920). They derived the “General method” of process calculation, which integrates the lethal effects by a graphical or numerical integration procedure based on the time–temperature data obtained from test containers processed under actual commercial processing conditions. Ball (1923) developed a mathematical procedure for determining the heat sterilization required for the safe processing of canned foods, which is known as the “Formula method.” This makes use of heat penetration (HP) parameters with several mathematical procedures to integrate the lethal effects of heat (Stumbo, 1973; Hayakawa, 1978; Ramaswamy et al., 1992). Over the years, Ball’s method has undergone rigorous evaluations, simplifications, and improvements (Ball and Olson, 1957). Despite its limitations, Ball’s method is widely used in the canning industry all around the world (Merson et al., 1978). Stumbo’s method eliminates some of the oversimplifications and assumptions used in the development of Ball’s formula method (Stumbo, 1973). Additional formula methods were developed by Hayakawa (1978) and Steele and Board (1979). These methods involving the solution of formulae for thermal process calculations have been widely used for many years in the food industry. The purpose of these is to estimate the process lethality of a given process, or alternatively to arrive at an appropriate process time under a given set of heating conditions to result in a given process lethality. Smith and Tung (1982) assessed the accuracy of the Ball, Stumbo, Steel and Board, and Hayakawa’s formula methods for determining process lethality in conduction-heated foods. They reported that Stumbo’s (1973) method gave the best estimates of process lethality under various conditions.

Determination of the time–temperature history of processed food has practical and safety implications. Navankasattusas and Lund (1978), have discussed methods for time–temperature profile evaluation and measurement of lethality in processed foods. Data on thermal process schedules, which indicate the $F_0$ value, time and temperature of the processing, are available in the literature (Lopez, 1996). Time–temperature histories may be derived by using direct measurements or by mathematical modeling (Tucker and Holdsworth, 1991).
3.5.6 Packaging Materials for Thermal Processing

Packaging material forms the most important component of thermal processed foods. It should be able to withstand the severe process conditions and should prevent recontamination of the product. Various packaging materials have been used historically starting from glass container to metal container, flexible retortable pouches, and rigid plastic containers (Figure 3.2).

3.5.6.1 Glass Containers

Glass is a natural solution of suitable silicates formed by heat and fusion followed by immediate cooling to prevent crystallization. It is an amorphous transparent or translucent super-cooled liquid. Modern glass container is made of a mixture of oxides namely, silica (SiO₂), lime (CaO), soda (Na₂O), alumina (Al₂O₃), magnesia (MgO), and potash in definite proportions. Coloring matter and strength improvers are added to this mixture and fused at 1350°C–1400°C and cooled sufficiently quickly to solidify into a vitreous or noncrystalline condition.

Glass jars for food packing have the advantages of very low interaction with the contents and product visibility. However, they require more careful processing and handling. Glass containers used in canning should be able to withstand heat processing at a high temperature and pressure. Breakage occurring due to “thermal shock” is of greater significance in canning than other reasons of breakage. Thermal shock is due to the difference in the temperature between the inside and the outside walls of the container giving rise to different rates of expansion in the glass wall producing an internal stress. This stress can open up microscopic cracks or “clucks” leading to large cracks and container failure. Thermal shock will be greater if the wall thickness is high. Therefore, glass containers in canning should have relatively thin and uniform walls. Similarly, the bottom and the wall should have a thickness as uniform as possible. More defects occur at sharp corners and flat surface and hence these should be avoided. Chemical surface coatings are often applied to make the glass more resistant to “bruising” and to resist thermal shock. Various types of seals are available, including venting and non-venting types, in sizes from 30 to 110 mm in diameter, and made of either tin or tin-free steel. It is essential to use the correct overpressure during retorting to prevent the lid being distorted. It is also essential to preheat the jars prior to processing to prevent shock breakage.

3.5.6.2 Metal Containers

Metal cans are the most widely used containers for thermal processed products. Metal containers are normally made of tin, aluminum, or tin-free steel.

3.5.6.3 Tinplate Cans

Tinplate is low-metalloid steel plate of can making quality (CMQ) coated on both sides with tin, giving a final composition of 98% steel and 2% tin. The thickness varies from 0.19 to 0.3 mm depending on the size of the can. Specified contents with respect to the content of other elements are: Carbon (0.04% - 0.12%), manganese (0.25% - 0.6%), sulfur (0.05% max), phosphorus (0.02% max),
silicon (0.01% max), and copper (0.08% max). The corrosive nature of tinplate depends principally on the contents of copper and phosphorous. The higher the contents of these metals, the greater the corrosiveness of steel. However, higher phosphorous content imparts greater stiffness to steel plate which is advantageous in certain applications where higher pressure develops in the container, for example, beer can.

Base plate for can making is manufactured using the cold reduction (CR) process. CR plates are more advantageous over hot reduced plates because of the following characteristics:

1. Superior mechanical properties—possible to use thinner plates without loss of strength
2. More uniform gauge thickness
3. Better resistance to corrosion
4. Better appearance

3.5.6.3.1 Tin Coating

The base plate is coated with tin either by the hot dipping or electrolytic process. The latter is more common because:

- It consumes less tin.
- It gives uniform coating.

In the electrolytic process pure tin is used as the anode, and base steel plate serves as the cathode. Depending upon the number of anodes used and the speed of the plate in the electrolytic cell, the pickup of the can can be regulated. Depending upon the different usages, the plate is given even or differential coating. In differential coating, the higher content of tin will always be on the surface coming into contact with the food.

Tinplate for can making has a steel base with four identical layers on either side.

- Steel base—provides strength and formability
- Tin—iron alloy FeSn₂ formed at the interface of steel and free tin layer acts as a bond between the two
- Passivating film of chromium oxide that prevents corrosion of tin
- Oil film, usually dioctyl sebacate or acetyl tributyl citrate, for easy handling and prevention of abrasion

3.5.6.3.2 Coating Weights of Tin

The coating weight of tin used to be expressed as units in lbs per basis box. A basis box consists of 112 sheets of size 20 in. × 14 in. The coating of 1 lb per basis box is known as E 100. When the weight of tin is 0.75 lbs per basis box, the plate is described as E 75. However, nowadays this is expressed as grams per square meter (GSM). The recommended differential coating for fish cans is D 11.2/5.6 which indicates a coating 11.2 GSM tin on the food contact side and 5.6 GSM on the external surface.

3.5.6.3.3 Lacquering

Tinplate for fish cans is given a coating on the food contact surface with a sulfur-resistant lacquer. The lacquers most commonly employed in fish cans are oleoresinous C-enamels. C-enamels contain zinc oxide that will react with the sulfur compounds released during heat processing producing zinc sulfide (white in color) preventing the formation of tin or iron sulfide.

Open top sanitary cans are generally of “three-piece” or “two-piece” construction. Three-piece cans consist of a cylindrical body with a soldered side seam and two ends attached to the cylinder by double seaming. Circumferential beads are made on certain type of can bodies, especially bodies
of larger cans to strengthen it by making it into columns of shorter can bodies. This is also a check against handling abuse and paneling pressures.

Cans ends are stamped out from the tinplate sheet simultaneously producing concentric expansion rings on them. The edges are curled, and the inside of the curl is lined with a sealing compound, which is generally a rubber solution, and is dried quickly. A film of rubber compound is left in the groove that will act as a gasket to ensure airtight sealing of the can.

3.5.6.4 Improvements in Can Making

Beaded cans permit the use of thinner plates for can making. To compensate for the loss in strength, mechanical strength is introduced into the can body by beading.

3.5.6.4.1 Cemented Side Seam

The cemented side seam imparts a better appearance to the can. The end seam also will be better formed. Thermoplastic cement, usually a nylon material, is the bonding material. This is applied to the pre-lacquered body beads, and a lap joint is formed which is bonded by application of heat followed by rapid cooling. The interior of the formed can is sprayed with lacquer.

3.5.6.4.2 Welded Side Seam

This is an alternative to soldering and has several advantages:

- Increased output
- Provides a lead-free side seam
- Improved flanging and double seaming, especially at the junction of the side seam
- Saves can material because of narrow overlap

3.5.6.4.3 Two-Piece Cans

Two-piece cans have a seamless body, and the ends are secured on top by double seaming. Advantages are

- Elimination of side seam and the seam on one end reduces the possibility of leakage
- Eliminates a potential source of lead contamination
- Aesthetic appeal because of the smooth profile and streamlined appearance
- Permits uninterrupted print decoration
- Bottom of the can may be designed and formed for better stackability
- Elimination of overlap at the two seams permits use of less metal

Two-piece cans are "drawn" cans made by cutting, drawing, and flanging from a plate in one operation. A aluminum or tinplate used shall be thicker and more ductile than that used for round cans. The two types are "Drawn and wall-ironed" (DWI) and "Drawn and redrawn" (DRD) cans.

3.5.6.5 Drawn and Wall-Ironed Can

This was first developed with aluminum in the early 1960s and the tinplate version became available by early 1970s. The process involves

- Blanking out a disc of metal from the sheet
- Drawing the disc into a cup
- Forcing it by means of a punch through a series of dies, each slightly smaller than the preceding one, thus elongating the wall by a stretching or ironing action. During this ironing process, the wall thickness is reduced with a corresponding increase in height
- Trimming the top to the standard height

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• Cleaning to remove lubricant and dust of metal
• Flanging
• Lacquering (by spraying)

3.5.6.6 Drawn and Redrawn Can
A blank disc is first drawn into a cup. A can of desired size can be made by a series of press operations, the number of operations being determined by the material used and the depth/diameter ratio of the can. A shallow can could be made by a first draw followed by a redraw; a deeper can by a draw followed by two redraws. In the DRD process

• The plate must be pre-lacquered to assist fabrication.
• The can wall remains substantially equal to the original plate thickness.
• A clear process which avoids the need for washing the cans after fabrication.

Two-piece cans are of different shapes—round, oval, and rectangular. Ordinary seamers for round cans will not be suitable for irregularly shaped cans. In the common seamers used for such cans, the can will remain stationary and two pairs of seaming rolls, the pair of opposite rolls in succession, will move round the can to make a seal. There is a possibility for uneven pressure on the seams and hence of leakage. This is partly overcome by the use of a good quality sealing compound in the cans' ends.

3.5.6.7 Necked-In Can
This is another modification where the can ends have the same diameter as the body. Such cans can be packed compactly.

3.5.6.8 Easy Open Ends
Easy open ends (EOE) are generally made of aluminum, though tinplate versions also became popular later. EOE consists of two parts, the lid and the tab. The tab is secured to the lid by means of an integral rivet. By pulling the tab, the central panel can be removed. Tinplate or aluminum ends are pre-punctured to provide a full aperture sealed by an adhesive strip of metalized polyester film or aluminum foil. Use of aluminum EOE on tinplate cans is limited because of the probability of bimetallic corrosion.

3.5.6.8.1 Aluminum Cans
The standard aluminum of 99.5%–99.7% purity is obtained by addition of one or more elements like magnesium, silicon, manganese, zinc, and copper (Mahadeviah and Gowramma, 1996). Lahiri (1992) described the suitability of different aluminum alloys for various food products. He also reported on the corrosion behavior of aluminum cans. Naresh et al. (1988) studied the corrosion behavior of aluminum cans by electrochemical studies and found that corrosion reaction is faster in plain aluminum cans compared to lacquered ones. Griffin and Sacharow (1972), suggested a suitable food grade lacquer coating for interior corrosion resistance. Balachandran et al. (1998) reported that the best promising alternative to tinplate has been considered as aluminum alloyed with manganese and magnesium. Lopez and Jimenez (1969) reviewed the use of aluminum cans for canning fruits and vegetable products. Srivatsa et al. (1993) studied the suitability of indigenously prepared aluminum cans for canning different food products. The advantages and disadvantages of aluminum alloys have been described by Balachandran (2001). Lakshminarayan (1992) reported that aluminum containers are 100% recyclable and biodegradable. Gargoming and Astier-Dumas (1995) studied the canning of vegetables and reported that the acidity of tomatoes resulted in greater migration of aluminum into the products. Ranau et al. (2001) studied the aluminum content in fish and fishery products and concluded that aluminum content of seafood does not present a significant...
health hazard. Ranau et al. (2001) studied the changes in aluminum concentration of canned herring fillets in tomato sauce and curry sauce. Figure 3.4 represents the aluminum can fitted with thermocouples for monitoring time-temperature history of the product.

Advantages of aluminum cans are

- Light weight, slightly more than 1/3 of the weight of a similar tinplate can
- Nonreactive to many food products
- Clear, bright, and aesthetic image
- Not stained by sulfur-bearing compounds
- Nontoxic, does not impart metallic taste or smell to the produce
- Easy to fabricate, easy to open
- Excellent printability
- Recyclability of the metal

However, aluminum cans are not free from some disadvantages like

- Thick gauge sheet needed for strength
- Not highly resistant to corrosion, acid fruits and vegetables need protection by lacquering or other means
- Special protection needed during heat processing to avoid permanent distortion
- Aluminum has a great tendency to bleach some pigmented products
- Service life is less than that of tinplate for most aqueous products

3.5.6.8.2 Tin-Free Steel Containers

Tin-free steel (TFS), apart from aluminum, is a tested and proven alternate to tinplate in food can making. It has the same steel substitute as tinplate. It is provided with a preventive coating of chromium, chromium oxide, and chromate–phosphate. TFS is manufactured by electroplating cold-rolled base plate with chromium in chromic acid. This process does not leave toxin substrate such as chromates or dichromates on the steel, and it can be formed or drawn in the same way as tinplate.

Advantages

- The base chromium layer provides corrosion barrier.
- The superimposed layer of chromium oxide prevents rusting and pickup of iron taste.
- Provides an excellent base for lacquer adhesion.
- Good chemical and thermal resistance.
- Tolerance to high processing temperature and greater internal pressure.
- Improved and more reliable double seam.

Disadvantages

- Low abrasion resistance; hence, compulsory lacquering.
- Difficult in machine soldering.
- The oxide layer needs removal even for welding.
- Limitations in use for acid foods.

An important problem associated with TFS can ends is scuffing of lacquer on the double seam. This may occur at the seamer or downstream at different stages of lacquering. TFS cans have been found quite suitable for canning different fish in various media. Thus, it holds good scope as an important alternate to tinplate cans.
3.5.6.9 Can Sizes

Can sizes are generally denoted by a trade name followed by their dimensions, diameter, and height, in that order, by their digit symbols. The first digit represents integral inches and the next two digits indicate measurements in sixteenth of an inch. Thus, a 301 × 309 can has a diameter of $3\frac{3}{16}$″ and height of $3\frac{1}{16}$″. Presently the dimensions are specified in millimeters. Trade names and dimensions of some cans popular for canning fish in India are given in Table 3.3.

### Table 3.3 Can Sizes Used in India

<table>
<thead>
<tr>
<th>Trade Name</th>
<th>Trade Dimensions</th>
<th>Over Seam Dimensions (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4½ oz prawn</td>
<td>301 × 203</td>
<td>77 × 56</td>
</tr>
<tr>
<td>8 oz prawn</td>
<td>301 × 206</td>
<td>77 × 60</td>
</tr>
<tr>
<td>1 lb jam</td>
<td>301 × 309</td>
<td>77 × 90</td>
</tr>
<tr>
<td>No. 1 Tall</td>
<td>301 × 409</td>
<td>77 × 116</td>
</tr>
<tr>
<td>8 oz Tuna</td>
<td>307 × 113</td>
<td>87 × 43</td>
</tr>
</tbody>
</table>

3.5.6.9.1 Rigid Plastic Containers

The rigid plastic material used for thermal processing of food should withstand the rigors of the heating and cooling processes. It is also necessary to control the overpressure correctly to maintain a balance between the internal pressure developed during processing and the pressure of the heating system. The main plastic materials used for heat-processed foods are polypropylene and polyethylene terephthalate. These are usually fabricated with an oxygen barrier layer such as ethylvinylalcohol, polyvinylidene chloride, and polyamide. These multilayer materials are used to manufacture flexible pouches and semirigid containers. The rigid containers have the advantage when packing microwavable products.

3.5.6.9.2 Retortable Pouches

The retort pouch is a relatively new type of container for packing foods, which enjoyed a rapid growth in demand since its introduction in the late 1950s. The U.S. Army promoted the concept of flexible retortable pouches for use in combat rations in the 1950s, which replaced the metal containers and glass jars. The choice of materials for the manufacture of retort pouches is very important. Packaging materials for retort pouches should protect against light, degradation, moisture changes, microbial invasion, oxygen ingress and package interactions, toughness and puncture resistance. It is very difficult to get a single material with all the desirable properties. Hence, laminates or co-extruded films are used (Rangarao, 1992). The most common form of pouch consists of 3-ply laminated material, with an outer polyester, middle aluminum foil and inner polypropylene layer. A retort pouch can be defined as a container produced using 2-, 3-, or 4-ply material that, when fully sealed, will serve as a hermetically sealed container that can be sterilized in steam at pressure and temperature similar to those used for metal containers in food canning. The materials used should be tough with good barrier property and heat sealability. Rubinate (1964) and Schulz (1973) suggested the material requirements for the retortable pouch. The development of the retort pouch has been considered as the most significant advance in food packaging since the metal can and has the potential to become a feasible alternative to the metal can and glass jars (Mermeistein, 1978). One of the early studies on the use of the pouch was by Hu et al. (1955). He reported the feasibility of using plastic film packages for heat-processed foods. Ishitani et al. (1980) reported the effect of light and oxygen on the quality changes of retortable pouch-packed foods. Lampi (1967) reported the microbiological problems faced in foods packed in retortable pouch. The review on the flexible packaging material including the history has been documented (Mahadeviah, 1976; Lampi, 1977; Leung, 1984; Gopakumar and Gopal, 1987;
Retort pouches have the advantages of metal cans and boil-in plastic bags. Configuration of some typical pouches are:

<table>
<thead>
<tr>
<th>Ply</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 ply</td>
<td>12 µ nylon or polyester/70 µ polyolefin</td>
</tr>
<tr>
<td>3 ply</td>
<td>12 µ polyester/12 µ aluminum foil/70 µ polyolefin</td>
</tr>
<tr>
<td>4 ply</td>
<td>12 µ polyester/12 µ aluminum foil/12 µ polyester/70 µ polyolefin</td>
</tr>
</tbody>
</table>

The 3-ply pouch is most commonly used in commercial canning operations. This is a three-layer structure where a thin aluminum foil is sandwiched between two thermoplastic films. The outer polyester layer provides barrier properties as well as mechanical strength. The middle aluminum foil provides protection from gas, light, and water. This also ensures adequate shelf life of the product contained within. The inner film which is generally polypropyline provides the best heat sealing medium.

The normal design of a pouch is a flat rectangle with rounded corners with four fin seals around 1 cm wide. A tear notch in the fin allows easy opening of the pouch. The rounded corners allow safe handling and help to avoid damage to the adjacent packs. The size of the pouch is determined by the thickness that can be tolerated at the normal fill weight. The size ranges (mm) available are:

<table>
<thead>
<tr>
<th>Code</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>130 × 160</td>
</tr>
<tr>
<td>A2</td>
<td>130 × 200</td>
</tr>
<tr>
<td>A3</td>
<td>130 × 240</td>
</tr>
<tr>
<td>B1</td>
<td>150 × 160</td>
</tr>
<tr>
<td>B2</td>
<td>150 × 250</td>
</tr>
<tr>
<td>B3</td>
<td>150 × 240</td>
</tr>
<tr>
<td>C1</td>
<td>170 × 160</td>
</tr>
<tr>
<td>C2</td>
<td>170 × 200</td>
</tr>
<tr>
<td>C3</td>
<td>170 × 240</td>
</tr>
<tr>
<td>D1</td>
<td>250 × 320 (Catering pack)</td>
</tr>
<tr>
<td>D2</td>
<td>250 × 1100</td>
</tr>
<tr>
<td>D3</td>
<td>250 × 480</td>
</tr>
</tbody>
</table>

**Advantages**

- Thin cross-sectional profile—hence rapid heat transfer—30%-40% saving in processing times—no overheating of the product near the walls
- Better retention of color, flavor, and nutrients
- Shelf life equal to that of the same product in metal can
- Very little storage space for empty pouches—15% of that for cans
- Easy to open

**Disadvantages**

- Pouches, seals more vulnerable to damage, can be easily damaged by any sharp material, hence necessitates individual coverage.
- With an over wrap cost that may go up above that of cans.
- Slow rate of production, 30 pouches in place of 300-400 cans per minute.
- Needs special equipment.
- Higher packaging cost and low output push up the cost of production.
3.5.7 Unit Operations in Thermal Processing of Fishery Products

Although a very wide variety of canned fishery products are available, there are very few operations that are unique to a certain variety of products. The initial handling steps, retort operation, and post-process handling steps are similar to all the products in a particular container. The major unit operations in canned fishery products are

1. Raw material handling
2. Pretreatment
3. Precooking or blanching
4. Filling into the container
5. Exhausting
6. Sealing
7. Retorting
8. Cooling
9. Post-process handling
10. Storing

Raw material handling is similar among the different products. The fish has to be maintained at a lower temperature from the time of its harvest till it is used for the preparation and maintained in a proper hygienic quality. The quality of the canned product is affected whenever the raw material is not maintained at a proper temperature and/or damaged physically between harvesting and thermal processing. It is usual practice to maintain fish in iced condition or in chilled seawater system or freeze the fish onboard the fishing vessel to maintain the quality and in the mainland, it is stored in cold storage maintained at −18°C or lower temperature, before it is used for canning purpose.

The pretreatment steps include washing, beheading, gilling, gutting, washing, and cutting into desired sizes. The main purpose of this step is to bring the raw material closer to the usable form. These pretreatment steps have to be carried out under strict hygienic conditions to prevent contamination from handling surfaces and from viscera.

Precooking, sometimes referred to as blanching is normally carried out in steam, water, oil, smoke, microwave, or a combination of these. Precooking reduces enzyme activity and improves sensory quality. The purpose of precooking is to remove excessive water content from the raw material which otherwise will be collected in the container after retorting. Precooking coagulates protein and helps in improving fish texture, imparting desirable flavor, and removing undesirable flavor. As precooking affects yield and sensory quality, the precooking conditions have to be optimized for different fishes.

Filling is the addition of products using filling media, and it can be either manual or automatic. It is a very important step as the variation in filling weight and filling temperature for hot fill products affects the rate of heat transfer. A part from maintaining proper filling weight, maintaining proper head space in the container is necessary to maintain the seal integrity as it can be affected by the thermal expansion of the product upon retorting.

Exhausting is an important step to remove the air present in the product as well as in the container. The air entrapped inside the container adversely affects the heat transfer capacity. It is also carried out to overcome the loss of oxygen-sensitive nutrients. Different methods are being followed in the industry for exhausting. These are hot filling, thermal exhausting, steam injection, and creating vacuum. In the hot filling method, the filling medium is heated to a specified temperature and filled in a hot condition, and the lids are closed immediately. In thermal exhausting, the filled containers are exposed to a specified temperature maintained either by steam as in an exhaust box (Figure 3.3) or exposed to boiling water. Exhausting is also done by injecting steam directly into the containers till it condenses, which ensures the removal of air. Exhausting is also achieved by creating a vacuum in the containers mechanically.
The success of the canning process is mainly assured with the formation of hermetic sealing of the containers whether glass, metal cans, or flexible retortable pouches. Failure in this critical step indicates the compromise of product safety and shelf stability. In cans, sealing is normally done using double seaming machines, either semiautomatic or fully automatic seaming machines (Figure 3.4). Once the sealing is over, the containers are arranged in the perforated trays or cages and loaded into the retort for thermal processing. Heat processing is normally carried out in the temperature range of 110°C–135°C for a specified time to achieve desired lethality and quality product. Retorting can be carried out either in steam, steam air (Figure 3.5), or water immersion retorts (Figure 3.6). After retorting for a specified time, cooling is done inside the retort by pumping cool potable water into the retort. Special attention is to be given while retorting in flexible retortable pouches to overcome the bursting of pouches due to pressure differences in and out of the pouches during cooling as there...
is a sudden drop in the pressure of the retort during the cooling process. This can be overcome by applying an overpressure of around 14 psi using air during the cooling process. Special care is also needed while performing heat processing in glass containers as this requires overpressure to overcome the damage to container. The cooling process is continued till the product temperature reduces to a minimum of 40°C. Upon cooling, post-process handling assumes importance as there is a chance of recontamination of the processed product if sufficient care is not taken. Chlorinated water has to be used to wash the containers after the cooling process maintaining proper hygiene and sanitation. Mechanical damage to containers has to be reduced during handling and storing. The washed and dried containers are stored in an ambient storage condition in a dust-free area.

### 3.5.8 Thermal Process Validation

Measuring the product temperature at cold point is the major activity of establishing a thermal process. Normally two stages of temperature measurement are employed for establishing a process,
whether by general method or mathematical method, for process value calculation. These are temperature distribution tests (TD) to identify the location of the zone of slowest heating in the retort, and HP tests to measure the temperature response at the product cold point.

3.5.8.1 Temperature Distribution Test

TD is the first step in HP studies. Generally, any system for thermal processing, whether retort, autoclave, or sterilizers, will contain regions in which the temperature of the heating medium is lower than that measured by the master temperature indicator. For example, with steam-air processes this can be caused by improper mixture and proportion, and in water immersion processes this can be caused by poor circulation of hot water. The location of these cold spots should be determined by performing “temperature (or heat) distribution” tests throughout the system. The concepts for TD testing are simple; however, the practicalities of making the relevant measurements are loaded with difficulty. A uniform TD throughout the retort does not necessarily indicate uniform lethaliies since uniform temperature does not guarantee uniform heat transfer. Therefore, the uniformity in temperature is the minimum that has to be studied and an additional heat distribution study is advisable if there are concerns about air entrapment or heat transfer coefficient reductions throughout a container load. For a steam retort, if the TD is unsatisfactory, it can normally be resolved by increasing the length of the period of air removal at the start of the process (venting). This contrasts with non-steam retorts where a large temperature range may be attributed to the design/loading of the retort, and simple corrective action is not possible.

3.5.8.1.1 When is TD Testing Required?

The TD within a retort should be tested on its installation, with intermittent retesting being required as factors change that could affect the retort performance. Retorts require, at a minimum, retesting in the event of any engineering work likely to affect the TD of the retort, such as

- Relocation of the retort or installation of another retort that uses the same services
- Modification to the steam, water, or air supply
- Failure of the key components (e.g., pumps and valves)
- Repair or modification to water or steam circulation systems within the retort
- If there are any doubts about the performance of the circulation system

In addition, if the load to be processed in a retort changes, retesting is required. Such circumstances include the use of

- New container sizes and shapes
- New container loading patterns
- New crate or layer pad design, or mode of use

It is also necessary to ensure that a retort’s performance does not deteriorate over a period of time, as corrosion or fouling in the steam, water, or air supply pipes builds up. Retort instrumentation and process records should be inspected regularly to identify when a TD problem has arisen. Regular retesting of a retort’s TD is a good practice to ensure that these faults are not overlooked.

3.5.8.1.2 Objectives of TD Tests

Although TD tests basically sample the performance of retort systems, in the industry they are frequently used as an opportunity to “audit” the installation to ensure long-term compliance (Figure 3.7). Good manufacturing practices for TD tests in batch retorts should be such that in steady-state operation, the temperature spread across the sterilizing vessel should ideally be $1^\circ$C.
or less. However, when this degree of control is not achievable due to design or characteristics of the equipment, any deviation from the limit should be allowed for the scheduled process.

If the retort uses condensing steam as the media, it is necessary to establish the time of vent in order that the distribution of temperatures across the retort is reduced to an acceptable limit. For venting trials, the following guidance are normally adopted:

- Note precisely the time at which the retort reaches 100°C.
- Do not close the main vent until all thermocouples reach the same temperature within 0.5°C.
- Close the vent and record when the master temperature indicator and chart recorder reach the process temperature.
- All thermocouples should indicate the same temperature within 1 min of the first thermocouple indicating that (process) temperature.
- Record the venting time as the number of minutes for which the main vent was left open after 100°C was reached on the thermocouple in the thermometer pocket.

The vent test is specific to condensing steam retorts and is required in addition to TD testing. For retort systems utilizing water or mixtures of steam and air, the TD tests are unlikely to result in a 1°C distribution in temperatures across the crates at the start of the hold phase. This is because of less favorable heat transfer coefficients with these heating media when compared with condensing steam and also the reduced quantity of heat available in, for example, a raining water system. It is common practice to quote a time into the hold phase by which the temperature distribution has stabilized to within 1°C, and to take this into account when establishing the hold time at constant temperature.

### 3.5.8.2 Heat Penetration Tests

HP is further subdivided into two stages when conducting the tests, first to locate the product cold point in the container and second to establish the process conditions that will lead to the scheduled process.

### 3.5.8.3 Locating the Product Cold Point

Within each food container there will be a point or region that heats up more slowly than the rest. This is referred to as the “slowest heating point” or “thermal center” and should be located using thermocouples (Figure 3.8) or some other sensing method positioned at different places in a food container (Figures 3.9 and 3.10). For foods that heat mainly by conduction, the slowest heating point...
**FIGURE 3.8** Different types of thermocouples used in the study.

**FIGURE 3.9** Aluminum and TFS cans fitted with thermocouple.

**FIGURE 3.10** Retortable pouches fitted with spacer and thermocouple.
Canning of Fishery Products

will be at the container geometric center. However, for foods that permit movement and can thus convect heat, this point is between the geometric center and approximately one tenth up from the base (in a static process). During a thermal process the food viscosity will decrease in response to increasing temperature, and as a result the slowest heating point will move downwards from the container geometric center. The critical point is when the lethal effect on the target microbiological species is at its most significant, which will be toward the end of the constant temperature hold phase. If the process utilizes rotation or agitation, the slowest heating point will be at the container geometric center.

3.5.8.4 Establishing the Scheduled Process Time and Temperature

The thermal process is finally established by measuring the temperature at the container slowest heating point for a number of replicates that are placed in the cold spot(s) of the thermal processing system. The data obtained are usually referred to as “heat penetration” data. Campden and Chorelywood Food Research Association (CCFRA) (1997) recommended three sensors from each of three replicate runs, and National Food Processors Association (NFPA), USA, suggests at least ten working sensors from a run, with replicate runs required where variability is found. The more common situation now is to take up to ten samples in two replicate runs, providing that the variability between runs is within acceptable limits. However, there can be limitations on the number of probes that can be inserted through a packaging gland or through the central shaft of a rotating system, and in these situations at least two replicate runs should be completed. Various methods can be employed to collect accurate HP data. The aim of an HP study is to determine the heating and cooling behavior of a specific product in order to establish a safe thermal process regime and to provide the data to analyze future process deviations. The design of the study must ensure that all of the critical factors are considered to deliver the thermal process to the product slowest heating point.

3.5.8.4.1 When is HP Testing Required?

The HP study should be carried out before commencing production of a new product, process, or package. Changes to any of the criteria that may change the time-temperature response at the product slowest heating point will require a new HP study to be conducted. The conditions determined in the study are referred to as the scheduled heat process and must be followed for every production batch, with appropriate records taken to confirm that this was followed. No further temperature measurement within containers is required in production, although some companies do measure temperatures in single containers at defined frequencies. However, the conditions used in single container testing will not represent the worst case, and it would be expected that the instrumented container would show a process value in excess of that measured by the HP study. Such data are intended to show carefulness and are more of a comfort factor. Figures 3.11 through 3.14 represent a variety of canned food products like sardine in oil and curry medium, smoked rainbow trout in oil medium, seafood mix in brine and tomato sauce medium, and tuna processed along with vegetables in TFS cans. Figures 3.15 through 3.18 represent the HP curves, and \( F_0 \) values of a value-added product.
Factors taken into consideration during HP tests are listed below:

1. **Process-related factors**
   a. Retort temperature history, heating, holding, and cooling temperatures and times: The accuracy of temperature measurements has a direct effect on lethality values, and temperature-measuring devices need to be calibrated to a traceable standard.
   b. Heat transfer coefficients: For processes heated by steam and vigorously agitated in boiling water, these are usually so high that no effect is observed; however, with other methods of heating, which have much lower values, it is important to estimate the effective values as accurately as possible.
   c. Come up time in steam, steam–air retorts, and filling stages for raining water or water immersion systems.
   d. Type of retort—stationary (batch or continuous), reel or spiral retort, hydrostatic retort.

2. **Product-related factors**
   a. Size of the individual pieces, composition of the food, product preparation method, ratio of solid to liquid content.
FIGURE 3.14 Tuna with green pea, baby corn, broccoli, and mixed vegetables in TFS cans.

FIGURE 3.15 Heat penetration characteristics and $F_0$ value for 16 × 20 cm retort pouch.
FIGURE 3.16 Heat penetration characteristics and $F_0$ value for 301 × 206 can.

FIGURE 3.17 Heat penetration characteristics and $F_0$ value for 17 × 30 cm retort pouch.

FIGURE 3.18 Heat penetration characteristics and $F_0$ value for 401 × 411 can.
b. Initial temperature of can contents: The uniformity of the initial filling temperature should be carefully controlled. The higher the initial temperature, the shorter the required process time.

c. Pre-retorting delay temperature and time: This is related to the filling temperatures and results from malfunctioning of the process, and delays affect the initial temperature of the can contents.

d. Thermal diffusivity of product: Most models are very sensitive to changes in the value of this property.

e. Z- and D-value of the target microbial species.

3. Container-related factors

a. Container materials: A part from tinplate and other metallic containers, all other materials, for example, plastics and glass, impede heat transfer into the container.

b. Container shape: The most rapidly heating containers have the largest surface area and the thinnest cross section.

c. Container thickness: The thicker the container wall, the slower the heating rate.

d. Headspace: This is of particular importance to agitated and rotary processes. The headspace and the rate of rotation need to be carefully controlled.

e. Container stacking: The position of the containers inside the retort and the type of stacking also affect the heat transfer to individual containers.

3.5.8.5 Effect of Thermal Processing on the Nutrition of Food

The primary objective of a thermal process is to produce a product that is free of pathogenic microorganisms. The target criterion for thermal processing of low-acid foods is to destroy spores of C. botulinum, which is the most heat resistant among the common food poisoning bacteria. Although thermal processing makes microorganisms and spores inactive, it may cause destruction of essential nutrients that leads to deterioration of product quality. Much attention has been given to maximizing quality retention for a specified reduction in undesirable microorganism. However, since the degradation of heat-sensitive vitamins and other quality factors such as color and texture will take place along with the microbial destruction, the optimum processing time and temperature must be utilized. Because of these safety and quality factors, care must be taken to avoid either overprocessing or underprocessing. Broek (1965) reported that moderate heating of fish had not affected the nutritive quality, while overheating led to loss of nutrients. In recent years, growing consumer awareness increased the interest in food quality during processing and storage (Lubuza, 1982). Researchers have studied the effect of thermal processing on the nutritive value of food. Bender (1972) and Ford (1973) reported the effect of thermal processing on the protein of fish. A reduction of 25% lysine during thermal processing was reported by Tooley and Lowrie (1974). Taguchi et al. (1982), and Tanaka and Taguchi (1985) reported an increase in peroxide value. A decrease in TBA value, TMA, and vitamin B1 (thiamin) for shrimp, rainbow trout, and Alaska Pollock (Chia et al., 1983) and a decrease in the TMA-O content of squids (Kolodziejska et al., 1994) after heat processing have been reported. Ma et al. (1983) reported a toughening during the initial stages of heating and softening during the later stage of processing for shrimps and mussels. Tanaka and Taguchi (1985) reported the changes in nutritional and sensory characteristics in canned fishery products. Fellows (1990) reported a reduction of about 10%-20% of the amino acids in canned products. Lou (1997) reported a decrease in purine content of shrimp especially adenine during thermal processing. A combination of tuna and vegetables like green pea and baby corn gave a better product than broccoli (Mohan et al., 2014). Thermal processing of tuna with vegetables like green pea, broccoli, and baby corn to an $F_0$ value of 8.0 min resulted in the reduction of 4.35%-15.22% in process time compared with tuna without vegetables for the same size cans. Retortable pouches had an advantage over metal cans in many ways. Processing in 16 × 20 cm retortable pouches resulted in 35.67% reduction in...
process time for equivalent lethality when compared with 301 × 206 cans (Mohan et al., 2006, 2008). For 17 × 30 cm retortable pouches, a reduction of 56.56% process time was obtained than the 401 × 411 cans. In the canned samples, the reduction of SH content was 50.54% more when compared with pouches. Although thermal processing affects some of the nutritional quality, it is by far the most successful preservation technology as it offers various advantages.

REFERENCES


