2 Food Biodeterioration and Methods of Preservation

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2.1 INTRODUCTION

Biodeterioration is defined as the breakdown of food by agents of microbiological origin, either directly or indirectly from products of their metabolism. This chapter discusses how the agents of food biodeterioration operate and the commercial methods available to counteract these agents in order to produce safe and wholesome packaged foods.

Contamination of packaged foods can arise from microbiological, chemical and physical sources. Microbiological sources can be present in foods prior to packing and on surfaces of packaging materials. Therefore, the shelf life will depend on their types and numbers, in addition to the hurdles to growth offered by the preservation techniques. Chemical sources usually arise from enzymes released by microorganisms in order to catalyse the breakdown of food into smaller compounds that can move through cellular walls of microorganisms. Physical contamination can on occasion introduce microorganisms, but does not in itself play a role in biodeterioration, and so physical contamination is not considered in this chapter.

The first section introduces the agents of biodeterioration, which includes enzymes and microorganisms. Enzymes are responsible for chemically breaking food down and can be presented naturally or introduced by microorganism activity. Growth conditions for microorganisms are presented, in addition to the factors that can be used to effect a reduction in their numbers. Bacteria and fungi warrant separate sub-sections because of the differing implications for introducing the organisms to the food and in methods for their destruction.

The second section outlines the principal methods of preserving packaged foods. Food preservation originated with traditional methods such as curing, salting and sugaring, which were developed before refrigeration was commonplace. Major commercial developments in preservation were the introduction of canning and freezing processes for extending the useable life of fruits and vegetables. These methods still form a substantial part of the food preservation business, with thermal processing being part of a combination process designed to present 'hurdles' to microbial growth.

Food preservation is intended to produce foods that are safe and palatable. To achieve this aim, pathogenic organisms must be eliminated or reduced to a safe level, and spoilage organisms must be reduced and maintained at a low level. Some foods are processed in order to achieve commercial sterility of the product and packaging such that pathogenic bacteria are effectively eliminated. Application of commercially used food preservation methods is presented.

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2.2 AGENTS OF FOOD BIODETERIORATION

2.2.1 Enzymes

Enzymes are complex globular proteins found in living organisms, which act as catalysts for speeding up the rate of biochemical reactions. Enzymes are naturally present in foods and can therefore catalyse reactions that lead to food biodeterioration. The action of enzymes can be used to beneficial effect by the food industry to produce food products and are, for example, used in the manufacture of cheese, extraction of juice from tomatoes and apples, and beverage clarification. However, it is usually necessary to inactivate enzymes (i.e. denature the proteins) present in food and on packaging surfaces using heat or chemical means in order to preserve and extend the shelf life of foods.

Fruit and vegetables are major sources of enzymes, and so they provide many examples of the nature and action of these agents of food spoilage. Enzymes associated with the deterioration of fruits and vegetables include peroxidase, lipoxygenase, chlorophyllase and catalase. Peroxidase is relatively heat-resistant and comprises a mixture of several enzymes of varying heat resistance. Some of these can be inactivated by mild heat treatments whereas others require several minutes at sterilisation temperatures to effect a complete peroxidase inactivation. During the ripening of fruit, the activity of some enzymes (e.g. pectinesterase and polygalacturanase) increases and causes a softening of the tissues as the cell wall materials are broken down.

In potatoes, enzyme inhibitors play an important role in balancing the rate of biochemical reactions in relation to sugar accumulation. This has commercial importance for the storage and conditioning of potatoes prior to processing, where the presence of reducing sugars is undesirable because they can lead to enhanced browning reactions that cause discolouration during cooking. The active enzyme is invertase, which produces reducing sugars from sucrose, especially at low temperatures. At higher temperatures the inhibitor is active and reducing sugars are prevented from forming.

Another problem with fruits and vegetables is enzymic browning, which results from damage or cutting of the surface and exposure to the air. This is due to the action of polyphenol oxidase, which in the presence of air oxidises phenolic constituents to indole quinone polymers. These reactions are particularly undesirable and several methods are used to prevent this type of browning. These include the use of citric, malic or phosphoric acids to inactivate the enzyme, using dilute ascorbic acid (vitamin C) solutions to reverse the oxidation reactions, or alternatively preventing oxygen from coming into contact with the food by immersion.

Other complex reactions can occur, for example, the *Rhizopus* mould causes softening of canned fruits by producing heat-stable pectolytic enzymes that attack the pectins in the fruit. *Mucor piriformis* and *Rhizopus* species also cause breakdown of texture in sulphite-treated strawberries as a result of a similar production of enzymes. Another mould species, *Byssochlamys*, has been considered responsible for the breakdown in texture of canned foods, particularly strawberries, in which it is sometimes found. This is a heat-resistant mould that requires temperatures in excess of 90°C for several minutes to adequately destroy it.

Enzymes are also produced during microbial spoilage of foods and many of these are involved in the breakdown of texture. A number of the microorganisms that secrete enzymes are moulds, however, there are bacterial species (e.g. *Bacillus subtilis*, *Bacillus amyloliquefaciens* and *Bacillus licheniformis*) that produce amylase, which is a heat stable enzyme. Amylase degrades starches, particularly naturally occurring starches, with the effect that the viscosity of the food is reduced as the carbohydrates are broken down into their constituent sugars. For example, amylase from *B. subtilis* is known to be the cause of recent thinning issues in canned white sauces and soups.

Failure to inactivate enzymes completely often shortens the storage life of packaged foods. This is less of an issue with canned foods, but is a factor to consider with frozen fruits and vegetables that receive only a blanching process prior to freezing. Blanching is intended to inactivate the majority of the enzymes without imposing excessive thermal damage to the food, hence it uses relatively mild temperatures (90–100°C) and short heating times (1–10 minutes). The renewed activity that often seems to be present in the thawed food after frozen storage is attributed to enzyme regeneration.

Yeasts and moulds are of particular concern for packaged foods because it is common for many species to produce spores as part of their reproductive cycle. Spores are easily carried in the air and can contaminate inside surfaces of exposed packaging. This usually occurs when the packaging is exposed to a factory environment, just prior to the filling operation. Care is needed when exposing the inside packaging surfaces to avoid contaminating what is otherwise a relatively clean surface. If no further process is given to the packaged food it is commonplace for the packaging to take place in a high care environment. An example of this is ready-to-eat cooked poultry products such as chicken portions.

2.2.2 Microorganisms

The term microorganism includes all small living organisms that are not visible to the naked eye. They are found everywhere in the atmosphere, water, soil, plants and animals. Microorganisms can play a very important role in breaking down organic material, but it is this very action degrading organic material that food preservation techniques aim to counteract.

Temperature is the most commonly used method to kill or control the numbers of microorganisms present within foods and on packaging surfaces. Five categories of temperature sensitivity are useful in defining the preferred temperature ranges for microorganism growth:

(i) *Psychrophilic* (cold loving), in which organisms can reproduce in chilled storage conditions, sometimes as low as 4°C, although 12–18°C is the preferred growth range. However, having evolved to survive in extremes of cold, these are the easiest to destroy by heat.
(ii) *Psychrotrophic* (cold tolerant), in which the optimum growth temperature is 20–25°C but slow growth can be achieved down to 8–10°C.
(iii) *Mesophilic* (medium range), in which the optimum growth temperature is 30–45°C. These are of greatest concern with packaged foods because many spore-forming organisms such as yeast and mould species are contained within the mesophile category.
(iv) *Thermophilic* (heat loving), in which the organisms have an optimum growth temperature of 45–60°C. In general, these organisms are only of concern if packaged foods are intended for use in temperate climates where the ambient temperature is sometimes in this growth range.
(v) *Thermoduric* (heat enduring), in which the organisms can survive above 70°C, but cannot reproduce at these temperatures.

2.2.2.1 *Bacteria*

Bacteria are single-celled microorganisms that normally multiply by binary fission, in which each cell divides into two cells following a period of growth. If conditions are favourable for

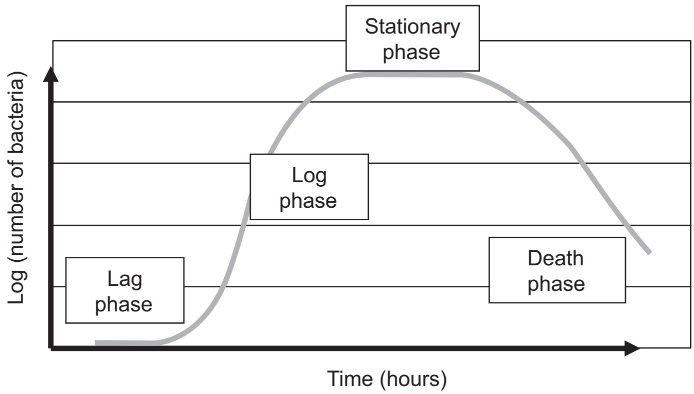

Fig. 2.1 Typical growth curve for a bacterium.

reproduction, one bacterium can divide by fission, so that after 11 hours there can be more than 10 million cells ($>1 \times 10^7$). This is a level in which organoleptic spoilage of the food is apparent due to production of off-flavours, unpleasant odours and slime, or it can result in toxin release. There are four stages in bacterial growth (see Fig. 2.1) that are important for food manufacture; these are the following:

(i) *Lag Phase*, during which the bacteria are acclimatising to their environment, which can be several hours long.
(ii) *Log Phase*, during which reproduction occurs logarithmically for the first few hours. Conditions for growth are ideal during this period.
(iii) *Stationary Phase*, during which the bacteria's reproduction rate is cancelled by the death rate caused by the production of undesirable by-products that poison the environment surrounding the bacterium.
(iv) *Mortality or Decline Phase*, during which exhausted nutrient levels and/or the level of toxic metabolites in the environment prevents reproduction, with the results that the bacteria gradually die off.

The simplest method of identifying bacteria is according to their appearance, which approximates to spherical (cocci), rod and spiral shapes. Cocci occur in different formulations, for example, diplococci in pairs, staphylococci in clusters, and streptococci in chains. Rod bacteria, or bacilli, mostly form chains. Cocci are small and can vary in size between 0.4 and 1.5 μm, whereas the larger bacilli are between 2 and 10 μm in length. Some cocci and many bacilli have the ability to move within their liquid environment by using flagella, which are similar in appearance to hairs. They enable bacteria to move away from their toxic metabolites. The most widely used method of identifying bacteria was introduced by the Danish bacteriologist Gram and is called Gram dyeing. Bacteria are divided into two main groups according to their Gram stain characteristics: red Gram negative and blue Gram positive.

Bacteria require water, proteins, carbohydrates and fats for growth. In addition, small quantities of vitamins and trace elements are needed to support and catalyse metabolism. Nutrients must be available in soluble form to aid transport through the cytoplasmic cell membrane. Large and complex organic molecules cannot pass through the membrane without first being broken down into smaller molecules. This is achieved by the bacteria releasing enzymes into the surrounding food that catalyses the break down of complex molecules into a form which can be used by the organism. An example of this is the release of amylase by various *Bacillus* species such as *B. subtilis*, *B. amyloliquefaciens* and *B. licheniformis*, which breaks down complex carbohydrates into simple sugars that can be absorbed through the cell membrane.

Water is essential for bacterial growth because it facilitates transport of small molecules through the outer cytoplasmic membrane of the bacterial cell via osmotic pressure gradients. Bacteria require higher levels of available water than yeasts or moulds. At 20% available water their growth is good, but it is limited when reduced to 10%, and at 5% there is no bacterial growth. The available water or water activity (a_w) is the amount of free water in a food and excludes moisture that is bound and unavailable to the microorganisms. Most bacteria cannot grow below an a_w of 0.91–0.94. Section 2.3.3 discusses methods of drying and control of a_w.

All bacteria need a supply of oxygen to oxidise their food to produce energy and for growth. Some bacteria obtain their oxygen directly from the air (aerobic bacteria), whereas others obtain oxygen from their food (anaerobic bacteria). The latter are usually killed when exposed to oxygen from the air. However, some bacteria can be facultatively anaerobic, which means they can consume oxygen from the air if present, but can also grow in its absence. Adjusting the atmosphere above a packaged food is used as a means to prevent bacterial growth, typically in combination with chilled storage as a further hurdle to growth. This allows foods to be manufactured with minimal or no heat processing, yet delivers an extended shelf life. Section 2.3.6 discusses modified atmosphere packaging in further detail.

Light is not an essential requirement for bacterial growth because the cells do not synthesise food using light energy. Instead, light has a destructive effect on bacteria because of the ultra violet (UV) component that causes chemical changes in the cell proteins. Bacteria prefer to grow in conditions where light is excluded. This effect is utilised by using UV light to sterilise bottled water where the limitation of transparency is not a restriction. A recent innovation for packaging sterilisation is high intensity pulsed light. This has the potential to effect surface pasteurisation by exposing the package to pulses of very high intensity light, of the order of 20 000 times that of the sun's intensity at the earth's surface. Section 2.3.7.6 discusses applications for pulsed light in more detail.

If the environmental conditions become adverse to the growth of certain bacterial species they have the ability to form a protective spore. Examples of conditions that can initiate spore formation are extremes of temperature, presence of adverse chemical environments (e.g. disinfectants), low quantities of available moisture and low concentrations of nutrients. During spore formation, the vegetative part of the cell dies and it forms again if the environmental conditions become favourable. Spores do not metabolise and so can lie dormant for years in conditions that could not support growth of the bacteria. This presents a challenge to the food processor, in that it is often necessary to kill both bacterial cells and spores that collect on the surface of exposed packaging. Destruction of spores requires more severe conditions of heat or disinfectant than that required to destroy vegetative bacterial cells.

Pathogenic bacteria

Several bacteria need consideration when designing a packaging and processing line. Of primary concern from a public health perspective are those that produce toxins such as *Clostridium botulinum*, *Listeria monocytogenes*, *Salmonella* spp., *Escherichia coli*, *Staphylococcus aureus*, *Bacillus cereus* and *Camplylobacter.* These can be controlled by the use of sterilising solutions and/or heat, with the aim of achieving the condition of commercial sterility for the packaged food. The most lethal of these is *C. botulinum*, which produces a toxin that attacks the nervous system. The industry is fully aware of the risks associated with this organism and has taken measures to prevent it being present in food.

C. botulinum spores only germinate in anaerobic conditions where there is available moisture as well as nutrients and the pH is over pH 4.5. Products with pH over 4.5 are often referred to as 'low acid' foods whereas products with pH of 4.5 and below are referred to as 'acid' foods. This critical pH limit is an important determinant as to whether heat-preserved foods receive a pasteurisation or sterilisation treatment. Sterilisation processes (typically 115–135°C) using heat have greater cooking effects on product quality than the relatively mild heat treatment of pasteurisation processes (typically 75–105°C). It is also important to ensure that spoilage organisms in a high acid food do not cause a shift in pH to the low acid level thereby allow the potential development of *C. botulinum.* Pasteurisation often requires foods to be acidified prior to thermal treatment (e.g. pickled vegetables). Section 2.3.6 discusses thermal treatment of foods in more detail.

Chilled foods have different target bacteria than those for thermally processed foods. Growth of most strains of *C. botulinum* are inhibited at refrigeration temperatures, however, there are psychrotrophic strains that can grow at low temperatures and are increasingly giving rise for concern in foods. This is of concern with sous-vide and vacuum-packed foods that only receive a mild heat treatment and rely heavily on precise control of chill temperatures to prevent spore outgrowth. *Listeria* is another bacteria that can survive and grow at low temperatures, but fortunately is killed by mild temperatures. The process used to achieve a 6-log reduction in *Listeria* is 70°C for 2 minutes, a process also applicable to *Salmonella* and *E. coli.* (Note that this group of bacteria are referred to as aerobic pathogens.)

Beneficial bacteria

Not all bacteria are pathogenic or the cause of food spoilage. Bacteria have been used to beneficial effect in fermentation and preservation processes to extend the shelf life of certain foods. One example that has been exploited for many years is the deliberate introduction of lactic acid bacteria for the fermentation of milk to produce yoghurts. Lactic acid bacteria can be either bacilli or cocci and are facultatively anaerobic. Their energy source during growth is the milk sugar lactose, and during fermentation this is converted to lactic acid. The result is that the level of acidity increases until a predetermined pH value is reached whereby the yoghurt is ready to be packaged. Lactic acid bacteria do not form spores, and the cells can be killed by heating to 70°C once the fermentation is complete. However, many types of yoghurt are marketed as having additional health attributes because they contain live lactobacilli that may have beneficial actions within the human digestive system. Section 2.3.5 provides further details on fermentation methods of preservation.

2.2.2.2 *Fungi*

Fungi are a group of microorganisms that are found in nature on plants, animals and human beings. Different species of fungi vary a great deal in their structure and method of reproduction. Fungi may be single-celled round or oval organisms such as yeasts or threadlike multi-celled structures such as moulds. The mould threads may form a network, visible to the naked eye, as seen, for example, on foods such as bread and cheese.

One of the most important medicines for treating bacterial infections, penicillin, is derived from the *Penicillium* mould. The appearance of the ascospore forming hyphae is that of a miniature green bush and is responsible for much of the green mould found in nature. The *Penicillium* family of moulds produces powerful lipases and proteases (fat- and protein-degrading enzymes) that make them key agents in the ripening of blue cheeses (*Penicillium roqueforti*) and Camembert (*Penicillium camemberti*). Another fungi, *Oospora lactis*, which displays characteristics of both yeasts and moulds, occurs on the surfaces of cultured milk as a white velvety coating. This is used for the ripening of soft cheeses (Tetra Laval, 1977).

Yeast cells are facultatively anaerobic and moulds almost exclusively aerobic. In the absence of oxygen, yeast cells break down sugar to alcohol and water, while in the presence of oxygen, sugar is broken down to carbon dioxide and water. The former reaction is used in the fermentation of alcoholic drinks, however, within the fermenting liquid, conditions lie between anaerobic and aerobic and so alcohol and carbon dioxide are produced.

Yeasts are single-cell organisms of spherical, elliptical or cylindrical shapes. The size of yeast cells varies considerably; for example, Brewer's yeast, *Saccharomyces cerevisiae*, has a diameter of the order of 2–8 μm and a length of 3–15 μm. Some yeast cells of other species may be as large as 100 μm. Yeast cells normally reproduce by budding, which is an asexual process, although other methods of reproduction can also occur. During budding, a small bud develops on the cell wall of the parent cell, with the cytoplasm shared by parent and offspring before the bud is sealed off from the parent cell by a double wall. The new cell does not always separate from its parent but may remain attached while the latter continues to form new buds. The new cell can also form fresh buds of its own. This can result in large clusters of cells attached to each other. Some yeasts can form ascospores, although these are part of the reproductive cycle and are quite different to bacterial spores where the spore is formed as means to survive adverse conditions. Hence yeast ascospores are easier than bacterial spores to kill on packaging surfaces by mild heat or sterilising solutions.

Moulds belong to a large category of multi-celled threadlike fungi. Moulds attach themselves to their food, or substrate, using long threads called hyphae. These are the vegetative part of the mould and grow straight up from the substrate. Like yeasts, moulds can also multiply by sexual or asexual reproduction, and this results in the production of a large numbers of ascospores. Sexual reproduction tends to be in response to changing environmental conditions, although this is not necessarily the case. Ascospores produced by sexual reproduction are more resistant to adverse conditions, and like bacterial spores, can lie dormant for some time.

One of the key sources of contamination of exposed packaging materials is from yeast or mould ascospores. This is because the ascospores are very small and light, are produced in huge numbers, and designed to be carried by air to new environments. Moulds introduced to packaging as ascospores are the usual source of post-process contamination of foods. For example, spoilage incidents with hot-filled jam in glass are usually caused by fungal growth on the jam surface. Either of steam treatment of closures, jar inversion immediately after closing or a post-pasteurisation process is required to prevent spoilage.

Conditions for the growth of yeasts and moulds are similar to those for bacteria. They can survive at lower available water levels, which is why bread is at risk to mould spoilage but not to bacteria. Fungi also have a greater resistance to osmotic pressure than bacteria and can grow in many commercial jams and marmalades. Fungi present on packaging surfaces and in food will be killed by the heat process applied to the packaged food, typically of the order 85°C for 5 minutes (CAMPDEN BRI, 1992), but once the jar is opened, airborne contamination from mould ascospores can occur. The moulds that grow in high sugar conditions do not form toxins and so the 'furry' growth colonies are unsightly but do not represent a public health risk.

Both yeasts and moulds are more tolerant to high acidity levels, with yeasts able to grow between pH 3.0 and 7.5, and moulds between pH 2.0 and 8.5. Optimum growth pH for fungi tends to be in the pH range 4.5–5.0. Few bacteria can survive these low pH conditions, although spores of *Alicyclobacillus* strains have been reported to exhibit extreme acid and heat tolerance. These bacteria are referred to as acidothermophiles, and have caused spoilage problems in fruit juices in which the pH can be as low as 3.0.

Generally, fungi are less tolerant to high temperatures than bacteria, an exception being ascospores from moulds such as *Byssochlamys fulva.* To produce a commercially sterile food, in which these ascospores are the target organism, requires extended heating at temperatures above 90°C. Strawberries are a common source of *B. fulva* but would be damaged by these levels of processing. Taking care to minimise *B. fulva* introduction is required to avoid excessive processing. Typically, most yeast or mould cells are killed after only 5–10 minutes heating at 60°C. Temperatures for optimum growth of fungi are normally between 20 and 30°C, which is the main cause for increases in spoilage outbreaks in food production during summertime.

2.2.3 Non-enzymic biodeterioration

One further category of biodeterioration worthy of mention is that of non-enzymic browning. An important reaction in foods that takes place between the sugar constituents and amine-type compounds results in progressive browning and the development of off-flavours. Examples of foods in which this type of quality deterioration takes place is dehydrated foods, especially dried potato and vegetables, fruit juices (both dried and concentrated) and wine. These complex chemical reactions are known as Maillard reactions after the French chemist who first investigated the interaction of sugars and amines in 1912. Essentially, the aldehyde groupings of the reducing sugars react with the free amino groups of amino acids to form furfuraldehyde, pyruvaldehyde, acetol, diacetyl, hydroxydiacetyl and other sugar-degradation compounds that in turn react with amines to produce melanoid-type macromolecules (brown pigments). Despite intensive research into this subject, the only successful way of inhibiting these reactions is by using sulphurous acid and sulphites. The levels of sulphur dioxide allowed in food products are strictly controlled by legislation and also by the amount that can be tolerated before the taste becomes unacceptable. In the case of dried products, these are sulphited immediately after or during blanching. The use of sulphites for this purpose does not involve the antimicrobial protection for which these compounds are used in other applications. It is important to note that sulphite treatment of any fruit or vegetable intended for canning needs to be very tightly monitored in order to avoid the risk of severe accelerated internal de-tinning.

2.3 FOOD PRESERVATION METHODS

Food preservation is aimed at extending the shelf life of foods. In most cases, it is the growth of either spoilage or disease-causing microorganisms that limits the length of time that a food can be kept, and most preservation techniques are primarily based on reducing or preventing this growth. However, there are other factors that limit shelf life, such as the action of naturally occurring enzymes within the food and natural chemical reactions between the constituents of the food, and these also have to be taken into consideration.

There are many methods that can be used to preserve foods, and it is common for these to be used in combination in order to reduce the severity of any individual method. This is referred to as 'hurdle' technology. The sections that follow describe in outline the most important preservation methods to the food industry. The importance of each method can be difficult to determine because of the synergistic effects of combining methods. For example, acidification of peach syrup with citric acid eliminates the possibility of growth of heat-resistant bacteria by lowering the pH, thereby changing the target microorganism to a less heat resistant mould. This reduces the severity of the pasteurisation treatment required and consequently reduces the cooking effect on peach texture.

The following sections describe the major food preservation methods that are applied to packaged foods.

2.3.1 High temperatures

Microorganisms and enzymes are both susceptible to heat, and appropriate heating regimes can be used to reduce, inhibit or destroy their activity. The degree of heat processing required to produce a product of acceptable stability will depend on the nature of the food, its associated enzymes, the numbers and types of microorganisms, the conditions under which the processed food is stored and other preservation hurdles used.

Manufacture of a heat-preserved packaged food can be broken down into two basic processes:

(i) The food is heated to reduce the microorganism numbers to an acceptably small probability of surviving pathogenic and spoilage organisms that can grow under the intended storage conditions.
(ii) The food is sealed within a hermetic package to prevent re-infection.

Preservation methods, such as traditional canning, seal the food in its package before the application of heat to the packaged food product, whereas other operations such as aseptic, cook-chill and cook-heat the food prior to dispensing into its pack.

2.3.1.1 *Blanching*

Blanching is a process designed to inactivate enzymes, and is usually applied immediately prior to other thermal preservation processes, for example using high temperatures (e.g. thermal processing) or low temperatures (e.g. freezing). Blanching is not designed to reduce the microbial population on the surface of foods but it will nevertheless reduce the numbers of organisms of lower heat resistance, such as yeasts, moulds and certain bacteria (e.g. *Listeria*, *Salmonella*, *E. coli*).

Without a blanching step, the shelf life of, for example, frozen vegetables would be substantially reduced as a result of chemical breakdown during storage. Freezing does not totally eliminate reactions at the storage temperatures used in commercial and domestic practice, but it does slow down those that rely on ionic transport. If enzymes were present in foods during their frozen storage life, the chemical reactions that cause food spoilage could occur, albeit at a slow rate. By inactivating the enzymes, these reactions cannot occur, and shelf life is extended.

In thermal processing of fruits and vegetables, the blanching step is similar, but its objective is to prevent further enzymic breakdown of the foods if delays occur prior to processing the foods. One further advantage of this step is that a proportion of the air enclosed within cellular material (e.g. in strawberries) is removed and in doing so the tendency for the fruit or vegetable to float is diminished.

2.3.1.2 *Batch thermal processing*

Canning is a term still widely used in the food industry to describe a range of thermal processes where the food is heated within its package to achieve a commercially sterile food. The concept of canning is to heat a food in a hermetically sealed container so that it is commercially sterile at ambient temperatures; in other words, no microbial growth can occur in the food under ambient storage conditions until the package is opened (Department of Health, 1994). Once the package is opened, the effects of canning will be lost and the food is regarded as perishable, and its shelf life will depend on the nature of the food itself.

Various packaging materials are encompassed within the phrase canning, which includes not only metal, but glass, plastic (pots, trays, bottles and pouches) and aluminium cans. Apart from fruits, most canned foods are sterilised, but there is a growing trend to apply additional hurdles to microbial growth that allow the processor to use a milder heat treatment referred to as pasteurisation (covered in more detail in Section 2.3.1.4).

The most heat-resistant pathogen that might survive the canning process of low-acid canned foods is *C. botulinum*. This bacterium can form heat-resistant spores under adverse conditions, which will germinate in the absence of oxygen and produce a highly potent toxin that causes a lethal condition known as botulism, which can cause death within seven days. As the canning operation generates anaerobic conditions (i.e. no oxygen), all canning processes target this organism, if no other effective hurdle to its growth is present.

In practical terms, the thermal process must reduce the probability of a single spore surviving in a can of low-acid product to one in one million million (i.e. 1 in 10^{12}). This is called a 'botulinum cook', and the standard process is 3 minutes equivalent at 121.1°C, referred to as F_0 3. The F_0 3 botulinum cook is not designed to reduce numbers of thermophilic organisms to a significant extent because these will not germinate from their spore forms during the shelf life. However, if the ambient conditions are likely to allow the growth of thermophilic organisms then a more severe process must be applied, of the order of 15–20 minutes at 121.1°C. F_0 3 is regarded as the absolute minimum, however, most canned foods receive a much higher heat treatment (F_0 6 or more) to deal with uncertainties over variations in product and/or thermal process control.

In the traditional canning process, the filled aluminium or metal cans are hermetically sealed with can ends attached by a double seaming operation, and the cans are heated in a batch steam retort. Care must be taken to ensure that the heat penetrates to the slowest heating point in the can, so that no part of the food is left under-processed. At the same time, it is desirable not to overcook the food, as this will result in reduced quality. A metal can is the ideal package from a processor's perspective because, relative to other packaging media, it offers high production speeds, pack size flexibility, and high compression strength to withstand physical abuse during processing and distribution.

After heating, the food needs to be cooled, and it is vital that no post-process contamination occurs through the package seals or seams. Therefore, maintaining the seal integrity is vital and there are strict regimes for container handling to minimise abuse to the seals. For example, cooling water must be of high microbiological quality, and container handling must be avoided while wet as this could result in re-contamination, with the water acting as a conduit for microorganisms. There is evidence that cans do not create an hermetic (gas-tight) seal while they are hot, because of expansion of the metal in the double seams. Good practice in canneries avoids manual handling of hot and wet cans to reduce the risk of post-process introduction of microbial contamination into the container.

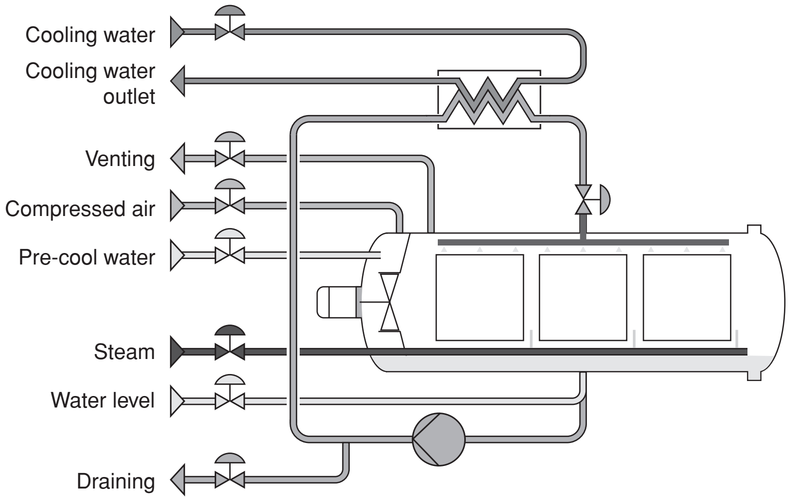

Fig. 2.2 Example of a batch retort operating on the steam and air principle. (Courtesy of Lagarde.) (For a colour version of this figure, see Plate 2.2.)

Thermal processing can be achieved using either batch retorts or continuous cooker-coolers. Batch retorts (see Fig. 2.2) operate with a variety of heating media, which includes condensing steam, mixtures of steam and air, water immersion, or water droplets that can be sprayed or rained onto the packs. These offer considerable flexibility for many combinations of food type and package.

By applying an air overpressure, above that of the saturated steam pressure, the package shape can be maintained through the process so that stress on the seals is reduced. This allows delicate packages such as pouches and trays to be processed. For glass jars, this prevents the lids from being forced off, and it ensures plastic packs retain their shape and size. Without air overpressure, flexible packs will expand, resulting in excessive stress on the seals and the possibility of packs bursting. Overpressure profile is one of the critical control points (CCPs) in a thermal process, and must be established by viewing or measuring pack deflection inside the retort. The retort pressure is adjusted in order to maintain the original pack shape. If this has not been set up correctly, there will be chances of damage to the sealing area, which may not be visible to the naked eye but sufficient for a microorganism to enter the pack.

A defect in the sealing area, for example a seam wrinkle, need only be a few microns in size to allow a bacterium to pass through. Since most packs, particularly metal cans, are closed to form an internal vacuum, which helps to eliminate oxidative deterioration of the food and reduce internal corrosion, the external pressure acts as a driving force moving water from outside of the sealing area to inside the pack. The first few minutes of cooling are also of particular concern, because of the substantial pressure swings in the retort that arise as steam condenses to leave a vacuum. This must be counteracted by the introduction of sterile air into the retort. A high proportion of pack damage is thought to occur during the onset of cooling but modern computer-controlled retorts have reduced this risk.

The baskets (or crates) within a batch retort can be rotated in order to induce mixing inside the food by end-over-end agitation of the packs. This increases the rate of heat transfer to the thermal centre (i.e. slowest heating point) of the pack. Typical rotation speeds can vary between

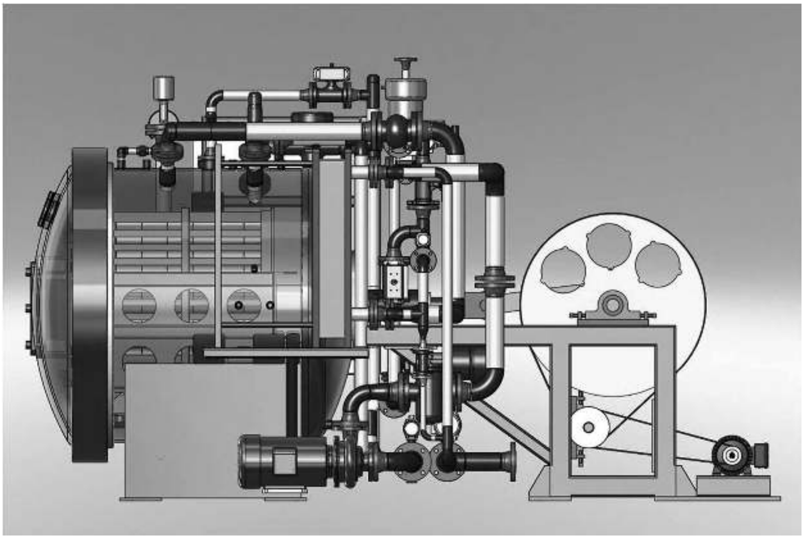

Fig. 2.3 Shaka retort using longitudinal agitation. (Courtesy of Allpax Products Ltd.) (For a colour version of this figure, see Plate 2.3.)

2 and 30 rpm, depending on the strength of the pack and the convective nature of the food inside the pack. For example, a plastic pouch containing rice would be rotated slowly (e.g. 2–5 rpm) so that the delicate pack and its contents are not damaged. However, the rotation is sufficient to reduce the process times to an extent that economic gains are made and measurable quality benefits are achieved.

A recent addition to batch retorts is the Shaka retort, which uses high frequency longitudinal agitation instead of end-over-end rotation. Reductions in process time are claimed to be significant. This has benefits in reducing energy use and process times, and in doing so increasing production efficiency. Fig. 2.3 shows the Shaka retort.

Continuous cooker-coolers come in two types; reel and spiral, and hydrostatic. Both use the ability of the metal can to roll along a pathway. A reel and spiral unit (see Fig. 2.4) forces the cans to rotate about their axis in the bottom third of a helical path where the gravity maintains contact between the cans and the metal can guides. This is known as fast axial rotation (FAR) and delivers a very rapid rate of heat penetration to the can centre. Soups, sauces and foods that can move within the can are processed in reel and spiral cooker-coolers. A hydrostatic cooker-cooler (see Fig. 2.5) does not invoke such dramatic rotation but instead carries the cans on carrier bars through various chambers. These include pre-heat at 80–90°C, sterilisation at 120–130°C, pre-cool at 80–90°C and final cooling to 40°C. The only rotation is a half-turn as the cans move between the chambers. Hydrostats are used for high viscosity foods where rotational forces cannot be utilised, for example solid petfoods and meat products.

Although metal cans are the traditional packaging material for thermally processed foods, other media including glass bottles/jars, plastic cans/bowls/pots/trays and flexible pouches are also filled and processed in a similar way. These are increasing in popularity because of the consumer benefits they offer, for example the possibility of microwave re-heating, product visibility and consumer handling characteristics. Each of these packs requires more care than metal cans, both during and after the process, because they are more easily damaged.

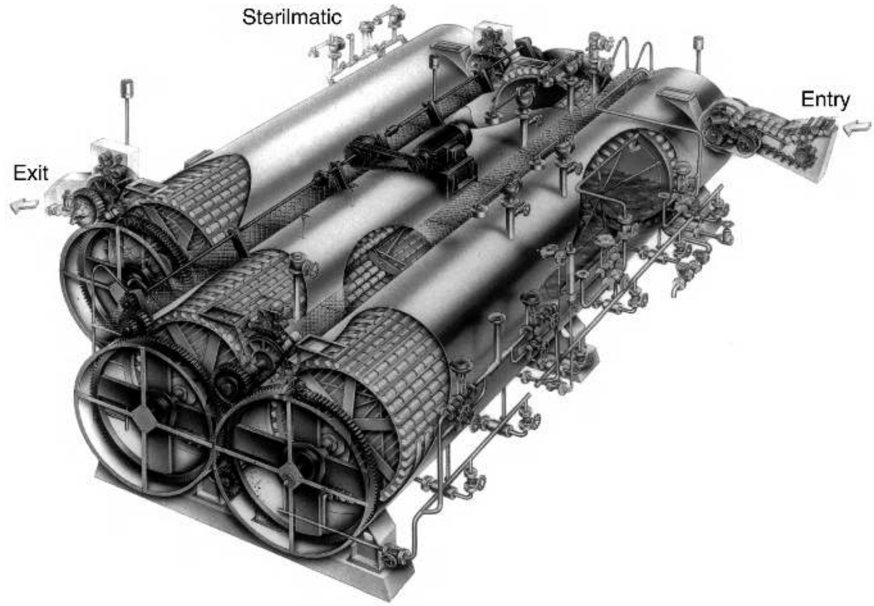

Fig. 2.4 Reel and spiral cooker-cooler for processing cylindrical food cans. (Courtesy of JBT FoodTech, formerly known as FMC FoodTech.)

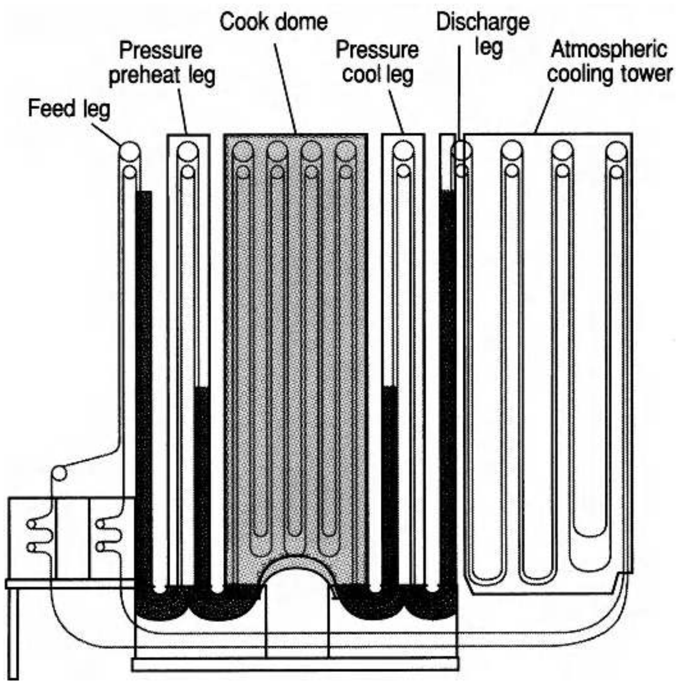

Fig. 2.5 Hydrostatic cooker-cooler for processing food cans. (Courtesy of JBT FoodTech, formerly known as FMC FoodTech.)

2.3.1.3 *Continuous thermal processing (aseptic and hot fill)*

The term UHT (ultra high temperature or ultra heat treatment) has been used to describe food preservation by in-line continuous thermal processing. In the aseptic filling process, UHT treatment is followed by filling into sterilised packages within a sterile environment. Examples of an aseptic package is the form, fill and seal (FFS) process, used for sachets, trays and pots, in which the packaging material is supplied on a reel and is formed into the package as part of the filling operation.

The food or beverage is sterilised or pasteurised in a continuous process in which it travels through a heat exchanger before being filled cold into the package. This technique is particularly suitable to liquid foods such as soups, fruit juices, milk and other liquid dairy products. Aseptic packaging is available in the formats of metal cans, plastic pots, plastic bottles, flexible packaging and foil laminated paperboard cartons. Since air overpressure is not required in this process the packaging does not need to be as strong as for retort-processed foods. Recent advances in aseptic filling have arisen in the drinks sector because of the complex package designs that are possible. These include ergonomically designed PET bottles and flexible pouches with sports caps.

Suitable heat exchangers for heating and cooling the foods are plate packs for thin liquids (see Fig. 2.6), tubular heat exchangers for medium viscosity foods (see Fig. 2.7) and scraped surface heat exchangers for high viscosity foods that may contain particulates (see Fig. 2.8). It is assumed that the thermal process is delivered solely within a holding or residence section that usually comprises a long length of tube. This does not take into account the high temperature periods at the end of heating and at the start of cooling, therefore allows generous safety margins. Sterilisation values are calculated from the holding tube outlet temperature and the residence time taken from the measured flow rate. Control of these parameters must be to very high levels of accuracy because of the high temperatures and short times (HTST) used.

One potential advantage of UHT processing is that of enhanced food quality, as the problem of overcooking can be reduced. Typical temperatures and holding times in a UHT process are of the order 140°C for a few seconds. At these elevated temperatures, the lethal kill of *C. botulinum* spores is substantial, whereas the rate of the cooking reactions is less significant. Many cooking processes, such as browning, are typified by higher z-values than for *C. botulinum* spores, in the range 25–33°C. Therefore increasing the processing temperature results in a more rapid microbiological kill rate but the reverse for cooking processes. In effect, UHT allows extremely short process times with minimal detriment to quality. This benefit is used in the production of sterilised milk and cream that would end up too brown (caramelised) with associated off-flavours if it was processed in pack. In the case of fruit juice and fruit drinks, one additional benefit is increased vitamin C retention, which is a heat sensitive substance.

Aseptic filling accounts for a high proportion of heat processed foods where high line speeds are appropriate. The packages are usually constructed within the sterile filling environment from reels of packaging material. For example, many fruit juices and juice drinks are packed in Tetra Brik Aseptic (TBA) foil-laminated cartons. Firstly, the liquid is pasteurised using a plate or tubular heat exchanger and secondly the carton material is sterilised using a combination of hydrogen peroxide and heat. The TBA system fills the pasteurised liquid into a continuous tube of sterilised unreeled carton material and the heat seal is made through the liquid prior to carton forming. This permits high production speeds to be achieved with a high assurance of seal integrity and, because normally there is no headspace, it is uses less packaging. A headspace can be induced if necessary – for example by nitrogen bubble dispersion in chocolate milk prior to filling and sealing – in order that the product can be thoroughly mixed by hand shaking the pack

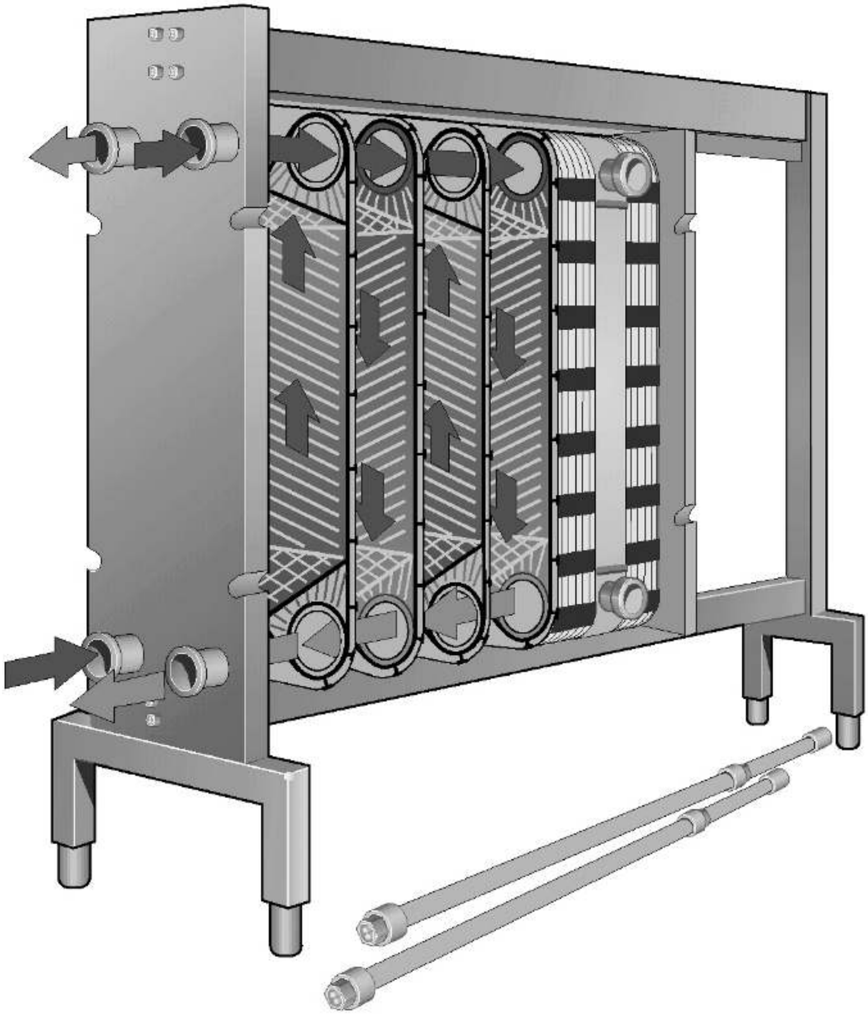

Fig. 2.6 Plate heat exchanger for processing thin liquids. (Courtesy of Tetra Pak.).

prior to consumption. The TBA system, however, imposes certain restrictions on the food types that can be filled, almost eliminating aseptic filling for foods containing discrete particulates that may not allow a correct seal to be formed. One possible solution is the SIG Combibloc carton system that involves a form-fill-seal of flat ready-made carton units and subsequent filling into the open-top carton.

Aseptic filling is best suited to liquid foods. One drawback to UHT processing of foods with particulates is that the particulates heat by conduction, which is a slow process. With high temperatures and short holding times, there is insufficient time to sterilise the centre of the particulates, and so one solution is to lower the temperature and increase the residence time. This minimises the benefits of UHT processing. One system that works well for particulates is ohmic heating, which relies on the electrical conductivity of particulates (refer to Section 2.3.7.2 for more details).

Fig. 2.7 Tubular heat exchanger for processing medium viscosity liquids, including those with small particulates. (Courtesy of Tetra Pak.) (For a colour version of this figure, see Plate 2.7.)

An alternative to aseptic filling is to fill the food hot and cool the filled package by immersing in water or under raining water. This is used for acid foods and some chilled soups and sauces. Heat resistant spores on the package surfaces will not be eliminated by the residual heat from the product, but the product acidity or the chilled storage conditions will prevent their outgrowth. Package types for hot filled products can be glass jars, cartons or plastic.

2.3.1.4 *Pasteurisation*

This is a heating regime (generally below 105°C) that aims to achieve commercial sterility by virtue of 'additional' factors that contribute towards preserving the food. The actual degree of heat process required for an effective pasteurisation will vary depending on the nature of the food and the types and numbers of microorganisms present. In certain cases, an extended pasteurisation treatment may be required to inactivate heat-resistant enzymes.

Milk is the most widely consumed pasteurised food in the UK and the process was first introduced commercially in the UK during the 1930s, when a treatment of 63°C for 30 minutes was used. Modern milk pasteurisation uses an equivalent process of 72°C for 15 seconds. This is

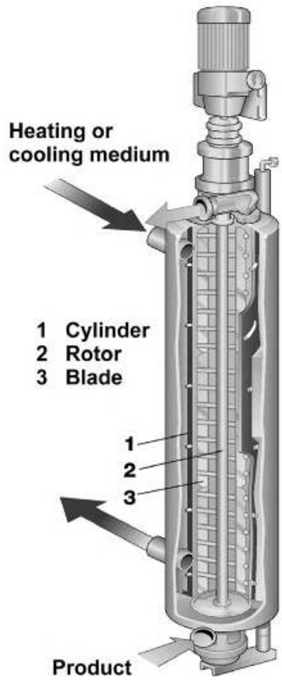

Fig. 2.8 Scraped surface heat exchanger for processing medium and high viscosity liquids, including those with particulates. (Courtesy of Tetra Pak.)

applied using a heat exchanger and the pasteurised milk is clean filled into glass bottles, plastic bottles or cartons. Product stability then relies on chilled storage.

Pasteurisation is used extensively in the production of many different types of food, such as fruit products, pickled vegetables, jams and chilled ready meals. Food may be pasteurised in a sealed container (analogous to a canned food), or in a continuous process analogous to an aseptic filling operation. It is important to note that pasteurised foods are not sterile and will usually rely on other preservative mechanisms to ensure their extended stability for the desired length of time. Chilled temperatures are often used, but some foods have a sufficiently high salt, sugar or acid content to render them stable at room temperature (e.g. pasteurised 'canned' ham).

Whereas sterilised packaged foods for ambient storage have shelf lives of 18–24 months, cook-chill foods typically have shelf lives measured in days, weeks or months. Further detail on the hurdles to microbial growth that allow pasteurisation processes to be applied can be found in the following sections. Many of these hurdles are used in combination with heat to deliver a commercially sterile packaged food.

2.3.2 Low temperatures

2.3.2.1 *Freezing*

Freezing of food does not render it sterile. Although the freezing process can reduce the levels of some susceptible microorganisms, this is not significant in the context of the overall microbial quality of the food. However, at commercial freezing temperatures (−18 to −24°C), all microbial activity is suspended and the length of time for which the food can be kept is dependent on other factors. It is important to note, however, that once a frozen food is defrosted, the viable microorganisms present will grow and multiply.

At freezing temperatures, enzymic activity may continue, albeit at a reduced rate, and over time could alter the organoleptic properties of the food. The potential problems with enzyme activity will depend on the particular food. For example, the sugar in peas is rapidly converted to starch once the pods are picked, and if not addressed, will result in a very un-sweet product. For this and related reasons, vegetable products are frozen within hours of harvesting and are blanched before freezing to ensure that enzymes are inactivated. The rate of freezing is important to the quality of the food. Rapid freezing in blast freezers is desirable to prevent the formation of large ice crystals that will tend to adversely affect the texture of the food by disrupting cell integrity in fruits and vegetables or degrading the muscle proteins of meat, fish and poultry.

Apart from enzymic activity, there are many chemical and physical changes that limit the shelf life of frozen food; examples include fat oxidation and surface drying, both of which may occur over a period of months. The interaction of the food and its package is critical in reducing these undesirable changes. Packaging for frozen foods uses a variety of materials and formats, including paper, plastic and metal. Unlike heat-processed foods stored under ambient conditions, the requirement for packaging materials is less stringent. Migration of gases such as oxygen through the packaging material has less effect on the food because the chemical reactions do not occur at significant rates, therefore the need for gas barrier materials is less critical. Also, the foods are frozen solid, which gives the pack greater rigidity, and there is no need for the packages to be commercially sterile as in aseptic filling.

Storage life of frozen foods tends to be dictated more by consumer handling than the effectiveness of the freezing processes. Typical domestic freezers operate at temperatures much higher than those used for production and distribution. Repeated freeze-thaw cycles damage the food structure around the edges and promote chemical and physical breakdown. Ice cream is an example of a high quality food that is manufactured to contain small (invisible) ice crystals within a complex matrix. However, the ice crystals grow in size as the food is abused, with the result that the smooth structure gradually breaks down and is replaced with a harder, coarse textured food with visible ice crystals.

2.3.2.2 *Chilling and cooling*

Chilling may be referred to as the process that lowers the food temperature to between a safe storage temperature of 0–5°C, whereas cooling is a more general term applied to the lowering of a food temperature. Chilled foods can present a greater risk to public safety than frozen foods because the low temperatures reduce the rates of microbiological and chemical deterioration of the food but do not stop them. In most chilled foods, it is microbial growth that limits the shelf life; even the slow growth rates that occur under chilled conditions will eventually result in microbial levels that can affect the food or present a potential hazard (see Table 2.1). This microbial growth can result in spoilage of the food (it may go putrid or cloudy or show the effects of fermentation), but pathogens, if present, may have the potential to grow and may show no noticeable signs of change in the food. Under the UK's Food Protection Act of 1990, a 'use by' date must be declared on labels for packaged chilled dairy, meat, egg, seafood and poultry products that must be distributed and retailed at 5°C or below.

Table 2.1 Minimum growth temperatures for selected pathogens.

Pathogenic microorganism	Minimum growth temperature (°C)
Bacillus cereus	4.0
Clostridium botulinum (psychrotrophic)	3.3
Escherichia coli O157 (and other VTEC)	7.0
Listeria monocytogenes	−0.4
Salmonella species	4.0
Staphylococcus aureus	6.7
Vibrio parahaemolyticus	5.0
Yersinia enterocolitica	−1.0

Source: Betts 1996.

To reduce microbial effects to a minimum, chilled prepared foods are usually given a pasteurisation heat process, sufficient to eliminate a variety of pathogens such as *Salmonella*, *Listeria* and *E. coli O157*. A process equivalent to 70°C for 2 minutes is considered to be sufficient, and will allow shelf lives of up to 10 days (FSA, 2008). If the pasteurisation regime is more severe, for example 90°C for 10 minutes (CAMPDEN BRI, 1992; FSA, 2008), it is possible to extend the shelf life beyond 10 days.

Chilling is also used to prolong the shelf life of many fresh fruit and vegetables. Here, low temperatures not only retard the growth of naturally occurring microorganisms (which might rot the food), but also slow down biochemical processes that continue after the food has been harvested. However, each individual fruit and vegetable has its own ideal storage temperature, and some are susceptible to chill injury. For example, storing bananas below 12°C will result in blackening of the skin.

Packaging for chilled foods shows a greater variety than for other preservation systems. This is because it is the microbiological growth within the food that limits the shelf life and not the interaction between the food and package. The package only has to survive a few days before the consumer uses it, which compares with frozen or canned foods where the pack has to offer protection to the food for up to three years. Thus, the barrier properties for short shelf life foods are less restrictive. A chilled food pack needs to be clean but not sterile, and this also opens up new packaging opportunities that cannot be realised with aseptic filling. Partial sterilisation of the open packs with sanitising solutions is sometimes used to reduce the microbial population, although it is more common for packs to receive just a water wash or air blast.

Exceptions to pack simplicity for chilled foods are found where hurdle approaches are used, for example when using modified atmospheres or in-pack pasteurisation. These are discussed in detail in the relevant sections that follow.

2.3.3 Drying and water activity control

All microorganisms need water to grow and so reducing the water in a food that is available to microorganisms is one way of slowing or preventing growth. Thus, dried foods and ingredients such as dried herbs and spices will not support microbial growth, and provided they are stored under dry conditions can have an expected shelf life of many months if not years. Many staple foods are available in dried form (e.g. cereals, pulses and rice) and, provided they remain dry, will be edible for a long period of time. The shelf life of breakfast cereals is usually limited by texture changes caused by moisture ingress through the packaging, with the food losing its

Table 2.2 Commercial drying methods with examples of food products.

Drying method	Food products	Packaging format
Spray dryer	Powdered milk, coffee granules	Plastic bottles, glass jars, tinplate cans, multiwall paper sacks
Freeze dryer	Granulated coffee	Glass jars
Perforated plate	Fruit, e.g. raisins, sultanas	Plastic film, laminated board
Fluidised bed	Peas	Cartonboard
Drum dryer	Breakfast cereals, flaked products	Plastic laminated Cartonboard, cartonboard with plastic inner bag.
Sun	Tomatoes, meat	Glass jar, packed in oil to prevent contact with moisture

crispness and becoming soft. Selection of suitable packaging materials is therefore critical in extending the shelf life of dried foods. Laminated paperboard with a plastic moisture barrier, such as polyethylene, is a common pack format for dried foods such as pasta, fruit and breakfast cereals, although alternative pack formats include moisture barrier bags and pouches.

Most dried foods achieve moisture levels that are low enough to prevent chemical reactions occurring, and in doing so, chemical deterioration is removed as a factor that affects shelf life. The moisture content of foods is measured by the equilibrium relative humidity (ERH). It represents the ratio of the vapour pressure of food divided by that of pure water, and is given the symbol a_w (water activity). As stated in an earlier section on microorganism growth, most bacteria cannot grow below a_w levels of 0.91, and yeasts cease growing at a_w levels of 0.85, and moulds at a_w levels of 0.81. The target a_w levels for dried foods are around 0.3, which is substantially below the value that supports microbial growth. Whether there is a killing effect at such low a_w levels is uncertain and probably depends on whether the microorganism can produce resistant spores in the time available when the moisture content is within growth limits. Rapid drying processes such as spray drying may not allow time for this to happen, but the traditional method of sun drying will involve a longer time as the food's moisture content decreases at a much slower rate that may be sufficient for spore production.

Various drying methods can be used in the production of dried foods (see Table 2.2). Choice of the method and the packaging format are dependent on the food and its intended use. Each of the listed methods can reduce the a_w level close to 0.3, and thus eliminate microbial and enzymic breakdown reactions.

A traditional method for reducing a_w levels in foods is to use sugar to generate an osmotic pressure gradient. Some foods such as jams and marmalades may contain fairly high levels of water, but much of this is 'tied up' or 'bound' (i.e. the food has a low water activity) by the sugar and pectin present in the jam and is not available for the microorganisms to use. As a result, traditional jams can be kept for many months without spoiling. Conversely, many low-sugar jams have to be refrigerated after opening, as the sugar levels are not sufficient to prevent microbial growth. Microorganisms present in the jam and on the packaging are destroyed during manufacture by applying a pasteurisation process, but airborne contamination from mould spores is introduced once opened. This is a good example of how the consumer-driven desire for foods with altered characteristics (i.e. jam with less sugar) has resulted in a food that has lost one of its major, original characteristics, a long-term stability at room temperature. Screw top glass jars and heat sealed plastic pots are common packaging types for foods that use osmotic pressure to control the a_w levels. The key criterion for the packaging is a high moisture barrier (and good heat resistance if hot filled) to prevent water ingress over the shelf life up to

18 months. Also, for glass jars, the top must be re-closable to provide an additional shelf life of a few weeks after opening.

2.3.4 Chemical preservation

The addition of specific chemicals to foods to inhibit microbial growth and chemical reactions is a major method of preserving food. Antimicrobial additives ('preservatives') receive a lot of attention, much of it being unjustly adverse. There are relatively few preservatives permitted for use in the UK and EU, and in many cases there are specific limits on how much can be used and in which foods. The use of some preservatives is limited to just a few types of food (e.g. nitrate and nitrite salts to specific meat, cheese and fish products). The two types of preservatives used most widely are sorbic and benzoic acids and their salts, and sulphur dioxide and its derivatives. There is currently a major consumer-led move to limit the foods containing preservatives and the reduce levels of preservatives used. This poses a significant problem for the food industry, as a reduction in preservative level either necessitates another preservation technique to be used (e.g. heating or freezing) or it results in a significant reduction in shelf life.

In addition to preservatives, antioxidants are widely used to prevent chemical deterioration of foods; this includes the rancidity caused by oxidation of fats, and the browning of cut vegetables caused by the formation of high molecular weight compounds due to the action of the enzyme polyphenol oxidase.

Introducing the preservative to a packaged food can be achieved in one of two ways. The most common is to mix the preservative into the food prior to filling. This is the method used in the production of soft drinks that require benzoate, metabisulphate and sorbate salts to inhibit microbial growth once the package (e.g. plastic bottles of juice concentrate) has been opened. Without the preservatives, yeasts and moulds will contaminate the juice, grow in the ambient storage conditions and very quickly cause it to spoil. This is why many packs, such as single-shot drinks bottles, do not possess a re-close facility.

Some meat products, for example canned ham and tongue, have nitrite salts and/or nisin added before the thermal process is applied. Their function is to allow a reduced thermal process to be given (a sub-botulinum cook, e.g. F_0 0.5–1.5), but avoiding excessive thermal degradation of the meat. An alternative method of introducing the preservative to the food is to integrate it into the packaging or introduce it as a component of the packaging. This is called 'active packaging' and is discussed in detail in Chapter 9 . Costs for active packaging materials are considerably greater than for conventional materials, therefore these packs are almost exclusive to foods that can command higher retail prices. Preservatives included in packaging are called bacteriocins. The antimicrobial agents are slowly released to the food or atmosphere above the food and will prevent microbial growth over the short shelf life. Extensions to shelf life of several days can be achieved by using active packaging, which has developed into a growth sector of considerable commercial value.

Some forms of chemical preservation are well-established and traditional techniques, as outlined below.

2.3.4.1 *Curing*

Strictly speaking, curing actually means saving or preserving, and processes include sun drying, smoking and dry salting. However, curing now generally refers to the traditional process that relies on the combination of salt (sodium chloride), nitrate and nitrite to effect chemical preservation of the food, usually meat, but also to a lesser extent fish and cheese. The method of preservation relies on the available water for microorganism growth being chemically or physically bound to the curing agent, and thus, not available to the microorganism. For example, salt achieves this by creating ionic bonds between the polarised hydrogen and hydroxide ions in water with the sodium and chloride ions from the salt.

In cured meat products, the salt has preservative and flavour effects, while nitrite also has preservative effects and contributes to the characteristic colour of these foods. Bacon, ham and gammon are cured pork products, and there are a number of variations on the curing technique. For example, the traditional Wiltshire curing of bacon (Ranken *et al*., 1997) involves injection of brine into the pig carcass, and immersion in a curing brine that contains 24–25% salt, 0.5% nitrate and 0.1% nitrite. The curing brine is used from one batch to another, being 'topped up' between batches, and is a characteristic deep red colour due to the high concentration of protein that accumulates.

Typical cured food products such as bacon, ham and fish are often shrink-wrapped in plastic film and stored under chilled conditions. Vacuum packaging is common because this increases the shelf life by reducing the rate of oxidative damage.

2.3.4.2 *Pickling*

This commonly refers to the preservation of foods in acid or vinegar, although the term can occasionally be applied to salt preservation. Most food poisoning bacteria (e.g. *C. botulinum*) stop growing at acidity levels below pH 4.5, the minimum level attained during the pickling process, although yeasts and moulds require a much higher degree of acidity (pH 1.5–2.3) to prevent growth.

A number of vegetables are pickled in vinegar in the UK, such as beetroot, gherkins and cucumbers, onions, cabbage, walnuts and eggs. In some foods, the raw or cooked material is simply immersed in vinegar to effect preservation, but in others, additional processes such as pasteurisation are required to produce a palatable and safe end product. For example, a typical process for pickled shredded beetroot involves steam blanching the beetroot to inactivate the betanase enzyme that degrades the red pigment (betanin) in the presence of oxygen, as well as steam flow closure and pasteurisation in a retort at 100°C.

Glass jars with regular twist-on/off (RTO) lug caps and fully internally lacquered tinplate cans are typical packaging for pickled and low pH foods. The package seal must not leak as pickle brines are very corrosive to the external surface of tinplate cans and, in the case of glass jars, rusting of tinplate cap lugs onto the glass thread may prevent cap removal. Also, the absence of a vacuum or poor vacuum levels in bottled pickles may serve to promote corrosion beneath the internal lacquer coating (i.e. under-film attack) and compound lining of caps thereby effecting leakage. Naturally occurring acids, such as lactic and citric acid, are added to a variety of foods in order to lower the pH to a level where *C. botulinum* cannot grow. While spores of this organism may be present in the foods, it is not a risk because the spores cannot germinate at pH levels below 4.5. Production of pasteurised foods with high acid / low pH is often achieved using glass as the packaging format. By applying hurdle technologies of low pH and mild heat, it is possible to produce high quality foods, and glass offers excellent visual characteristics combined with consumer appeal.

2.3.4.3 *Smoking*

This is another traditional preservation method that relies on chemicals to effect preservation of the food. Meat smoking derives from the practice of hanging meats in a chimney or fireplace to dry out. This has a variety of effects: the meat is partially dried, which itself assists with preservation, but polyphenol chemicals in the smoke has direct preservative and antioxidant effects, and imparts a characteristic flavour on the food.

Smoked salmon is an example of a food in which brining is used in combination with smoking to give an end product with an extended shelf life under chilled conditions. Three preservation technologies (brining, smoking and low temperature) provide the hurdles for microbial growth. Packaging for smoked foods is usually in transparent shrink-wrapped plastic film that excludes air from the package and provides an odour barrier to prevent loss of flavour from the product.

Many modern manufacturers now use synthetic smoke solutions into which the food is dipped in order to achieve higher production rates and exert better control over penetration of flavours as well as preservative chemicals into the product. It also serves to limit the presence of undesirable poly-aromatic hydrocarbons. Liquid smoke does not dry out the food as does the traditional smoking method, and when combined with the different chemical profile deposited on the food is likely to result in a different microbial population on the food surfaces. Liquid smoked products may spoil in a different way than their traditionally smoked equivalents.

2.3.5 Fermentation

Fermentation represents one of the most important preservation methods in terms of the calorific proportion of food consumed by an individual, which can be as high as 30%. In fermented foods, preferred microorganisms are permitted or encouraged to grow in order to produce a palatable, safe and relatively stable product. The microorganisms prevent or retard the growth of undesirable spoilage or pathogenic organisms, and may also inhibit undesirable chemical changes. There are three main types of fermentation in the food industry:

(i) Bacterial fermentation of carbohydrates, as occurs in yoghurt manufacture.
(ii) Bacterial fermentation of ethanol to acetic acid (as in vinegar production).
(iii) Yeast fermentation of carbohydrates to ethanol (as in beers, wines and spirits).

In yoghurt production, the milk is first pasteurised to reduce the natural microbial population and so destroy pathogens before the bacterial cultures are added. As fermentation progresses, lactic acid is produced and the pH drops to around 4.0–4.3. At these pH levels, few pathogenic bacteria can grow and the yoghurt is ready to be cold-filled into heat sealed plastic pots. Many of the filling systems for yoghurts operate on the form-fill-seal principle, in which the packaging is presented to the filler in two reels, and the pots are blow moulded within the filler environment. Although a yoghurt operation does not need to be aseptic (the yoghurt has a low pH and short chilled shelf life), this type of packaging machine could easily be converted to operate in aseptic conditions. Long, ambient shelf life yoghurts are filled in this way.

2.3.6 Modifying the atmosphere

This is a technique that is being increasingly used to extend the shelf life of fresh foods such as meat, fish and cut fruit, as well as various bakery products, snack foods and other dried foods. Air in a package is replaced with a gas composition that will retard microbial growth and the deterioration of the food. For example, grated cheddar cheese for retail sale is packed in an atmosphere of 30% carbon dioxide and 70% nitrogen. In most high water foods, it will be microbial growth that is inhibited because the carbon dioxide dissolves into surface moisture of

Table 2.3 Typical gas mixtures use in MAP of retail products.

Food product	**Gas mixture**
Raw red meat	70% O_2; 30% CO_2
Raw offal	80% O_2; 20% CO_2
Raw, white fish and other seafood	30% O_2; 40% CO_2; 30% N_2
Raw poultry and game	30% CO_2; 70% N_2
Cooked, cured and processed meat products	30% CO_2; 70% N_2
Cooked, cured and processed fish and seafood products	30% CO_2; 70% N_2
Cooked, cured and processed poultry products	30% CO_2; 70% N_2
Ready meals and other cook- chill products	30% CO_2; 70% N_2
Fresh pasta products	50% CO_2; 50% N_2
Bakery products	50% CO_2; 50% N_2
Dairy products	100% CO_2
Dried foods	100% N_2
Liquid foods and drinks	100% N_2

Source: Air Products 1995.

the product to form a weak acid, carbonic acid, and the absence of oxygen prevents the growth of aerobic spoilage bacteria and moulds. However, in dried foods, the onset of rancidity and other chemical changes can be delayed. The exact composition of the gas used will depend entirely on the type of food being packaged and the biological process being controlled (Day, 1992; Air Products, 1995). Modified Atmosphere Packaging (MAP) is generally used in combination with refrigeration to extend the shelf life of fresh, perishable foods (see Table 2.3 for typical gas mixtures used for selected foods). Most MAP foods are packaged in transparent film to allow the retail customer to view the food.

There are several techniques related to MAP that are worthy of mention. Unprocessed fruit and vegetables continue to respire after being packed, consuming oxygen and producing carbon dioxide. Using packaging with specific permeability characteristics, the levels of these two gases can be controlled during the shelf life of the food. Alternatively, active packaging can be used in which chemicals are incorporated, for example to remove gases or water vapour from the package.

An alternative to controlling or modifying the atmosphere is vacuum packaging, where all of the gas in the package is removed. This can be a very effective way of retarding chemical changes such as oxidative rancidity, but care needs to be taken to prevent the growth of the pathogen, *C. botulinum*, which grows under anaerobic conditions. A specific pasteurisation process, referred to as the 'psychrotrophic botulinum' process, is applied to the packaged food to reduce its numbers to commercially acceptable levels. By using vacuum packaging in combination with mild heat and chilled storage, greatly extended shelf lives can be achieved. This is the basis of 'sous-vide' cooking, which originated in France as a method of manufacturing high quality meals for restaurant use with up to 42 days shelf life when stored below 3°C. The process times and temperatures have evolved since the original sous-vide concept of pasteurising at 70°C for 40 minutes, and the target process is now 90°C for 10 minutes. Cleanliness of the packaging materials is a key requirement to achieve the extended shelf life.

2.3.7 Other techniques and developments

Food manufacturers are continually looking for new ways to produce food with enhanced flavour and nutritional characteristics. Traditional thermal processes tend to reduce the vitamin content of food and can affect its texture, flavour and appearance. Some of the commercialised systems are mentioned in the sections that follow. In addition to these, ultrasound, pulsed electric field, and high intensity magnetic field systems are all being actively investigated. In the UK, before any completely novel food, ingredient or process can be marketed, it has to be considered by the Advisory Committee on Novel Foods and Processes (ACNFP). The primary function of the ACNFP is to investigate the safety of novel food or process and to advise government of their findings. The European Union has also formulated 'Novel Foods' legislation.

2.3.7.1 *High pressure processing*

High pressure processing (HPP) was originally considered in the 1890s, but it was not until the 1970s that Japanese food companies started to develop its commercial potential. Pressures of several thousand atmospheres (500–600 MPa) are used to kill microorganisms, but there is little evidence that high pressure is effective on spores or enzymes. Thus, chilled storage or high acidity are essential hurdles in preventing microbial growth. Jams were the first products to be produced in Japan, and the process is now being used commercially in Europe and the USA. Product types now include meats, fish and shellfish, heat sensitive sauces such as avocado dips, fruit juices and smoothies. Packaging tends to allow the product colour to be visualised, therefore transparent plastic films are common.

2.3.7.2 *Ohmic heating*

Ohmic heating achieves its preservation action via thermal effects, but instead of applying external heat to a food as with in-pack or heat exchangers, an electric current is applied directly to the food. The electrical resistance of the food to the current causes it to heat it up in a similar way to a light bulb filament. The advantage is that much shorter heating times can be applied than would otherwise be possible, and so the food maintains more of its nutritional and flavour characteristics. The limitation is that ohmic cooling, or some other means of effecting rapid cooling, cannot be applied and so cooling relies on traditional methods that are slow in comparison with ohmic heating.

Foods containing large particulates are suited to ohmic heating because the electrical properties of the particulate and carrier liquid can be designed so that the particulate heats preferentially. The only commercial ohmic heater in operation in the UK (at the time of writing) is used to pasteurise fruit preparations, in which good particle definition is a key requirement. The packaging takes the form of stainless steel tanks that are transported to yoghurt manufacturers for inclusion in yoghurts, or plastic Pergall bags for food service use.

Most commercial ohmic applications are for high acid foods so that there is no requirement for aseptic filling. The technology has yet to find its niche market and the increase in applications has been slow. Nevertheless, for a high acid food with large particulates, ohmic heating confers significant quality benefits when compared with conventional heat exchangers. One application that has yet to be explored fully is the use of ohmic heating for achieving the fill temperatures prior to hot filling into jars, cans or plastic packages. Hot filled products can be designed so they receive no further process and cooling occurs within the filled package. This is gentle on the particulates.

2.3.7.3 *Irradiation*

Irradiation has seen much wider applications in the USA than in the UK where public opinion has effectively sidelined it. In the UK there is a requirement to label food that has been irradiated or contains significant irradiated ingredients. In addition to killing bacterial pathogens, such as *Salmonella* on poultry, it is especially effective at destroying the microorganisms present on fresh fruit such as strawberries and thus markedly extending their shelf life. It can also be used to prevent sprouting in potatoes. Its biggest advantage is that it has so little effect on the food itself that it is very difficult to tell if the food has been irradiated.

Irradiation also has some technical limitations, in that it is not suitable for foods that are high in fat, as it can lead to the generation of off-flavours. The only commercial foods that are currently licensed for irradiation in the UK are dried herbs and spices, which are notoriously difficult to decontaminate by other techniques. A major application for irradiation is in decontaminating packaging. The Pergall bags used for filling ohmically heated fruit preparations are irradiated to destroy microorganisms.

2.3.7.4 *Membrane processing*

Membrane processing has been used for many years in the food industry for filtration and separation processes, usually taking the form of porous tubes, hollow fibres or spiral windings, and ceramics. The membrane retains the dissolved and suspended solids, which are referred to as the concentrate or retentate, and the fraction that passes through the membrane is referred to as permeate or filtrate. The product can be either permeate (e.g. clarification of fruit juices or wastewater purification) or concentrate (e.g. concentration of antibiotics, whey proteins), or in occasional circumstances both. By selection of the membrane pore size it is possible to remove bacteria from water or liquid foods, and in doing so cold pasteurise the food. Commercial examples are the cold pasteurisation or beer, fruit juices and milk. Since the membrane is used to remove the microorganisms in the food, those present on the packaging surfaces must be killed using sterilisation solutions and/or heat.

2.3.7.5 *Microwave processing*

Microwave processing, like ohmic heating, destroys microorganisms via thermal effects. Frequencies of 950 and 2450 Hz are used to excite polar molecules, which produces thermal energy and increases temperature. On the continent, a small number of microwave pasteurisation units are in operation, primarily manufacturing pasta products in transparent plastic trays. Heat generated by the microwaves pasteurises the food and the package together, and the products are sold under chilled storage to achieve extended shelf lives. Benefits of rapid heating can result in improved quality for foods that are sensitive to thermal degradation. The technology has not received widespread adoption because of the high capital costs of the equipment and the wide distribution in temperatures across a package.

Microwave sterilisation has not developed much because of the need for air overpressure to maintain the shape of the flexible packages during processing. This creates complications with continuous systems in that transfer valves are required between the chambers.

Domestic microwave use has a far greater impact on the food industry, with a very wide range of foods available in microwave re-heatable packaging. Package design can be complex, utilising susceptor technology to shadow regions that lead to more uniform re-heating performance. Research into methods to enhance the desirable browning and crisping of certain foods are beginning to find their way into commercial packages.

2.3.7.6 *Pulsed light*

This technology shows potential for packaging surface decontamination. It uses very high intensity light in the visible spectrum, of the order of 20 000 times the intensity of the sun at

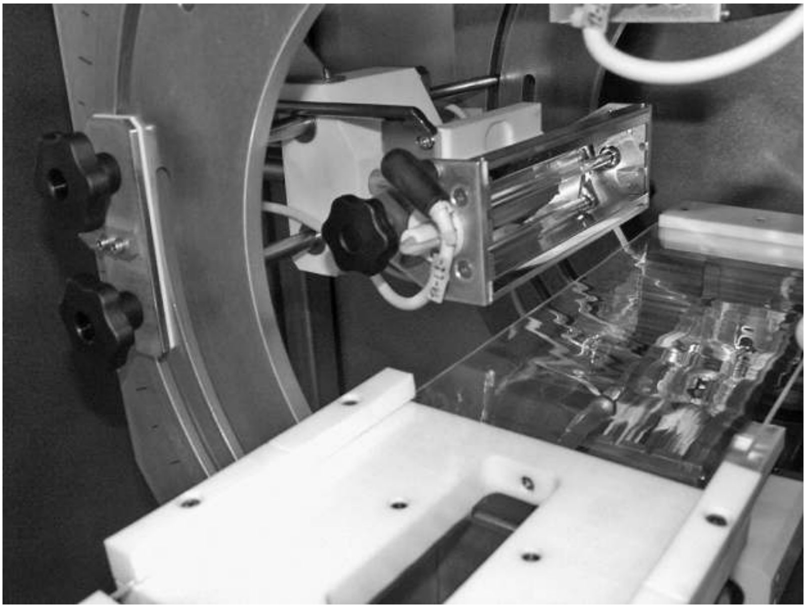

Fig. 2.9 Pilot pulsed light equipment for surface decontamination. (Courtesy of Claranor.) (For a colour version of this figure, see Plate 2.9.)

the earth surface. Hence, the packages receive the pulses of light within a closed chamber to protect the workers from damage (see Fig. 2.9). Commercial units are available from several manufacturers, although applications for the technology are still under investigation. One such application is pasteurisation of bottle caps used for water.

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