16

Food Preservation

Food preservation can be defined as the science, which deals with the prevention of decay or spoilage of food, thus allowing it to be stored in a fit condition for future use. The process used varies with the length of storage intended. It may be as simple as boiling milk so that it may keep for 24 hours or pickling of mango or lemon where the intended period of storage may be as long as a year.

Importance of Food Preservation

Food supply has to keep pace with the needs of the population. There is always a shortage of food in developing countries like India because of the demands of the increasing population. Increasing food production to meet this shortage results in wastage due to inadequate facilities available for storage and preservation. It is therefore, important to improve and expand facilities for the storage and preservation of food. Preservation of food helps in:

1. increasing the shelf-life of foods thus increasing the supply.
2. making the seasonal food available throughout the year.
3. adding variety to the diet.
4. saving time by reducing preparation time and energy.

Preservation increases availability of foods, thus improving the nutrition of the people. Availability of seasonal foods throughout the year also helps in stabilizing prices of such foods.

Food Spoilage

Food spoils, due to deteriorative changes that occur in it, that make it inedible or harmful. Foods change from the time of harvest, catch or slaughter. These changes may result in making the foods unfit for human beings.

There are several causes of food spoilage. These are

1. Growth of microorganisms, which bring, about undesirable changes.
2. Action of enzymes present in the food.
3. Oxidative reactions in the food.
4. Mechanical damage to the food (e.g., bruising of apples, bananas, mangoes, tomatoes).
5. Damage due to pests (e.g., insects and rodents).

Foods vary greatly in the length of time for which they can be held in their natural form without spoilage. For purposes of food preservation, foods are classified as perishable, semi-perishable and non-perishable. Perishable foods such as milk, meat, sea foods and many fruits and vegetables begin to deteriorate almost immediately after harvest if not preserved. These foods have a high moisture content and are highly susceptible to spoilage.

Microbial Spoilage

A number of moulds, yeasts and bacteria are known to cause food spoilage. Some of the micro-organisms exist both in active (vegetative cells) and dormant (spores) state. Spores, which are dormant cells, are more resistant to heat or other agents used to destroy micro-organisms than the vegetative cells.

Moulds You must have seen the fuzzy or cottony growth on chapati, bread or cooked rice. This is mould growth, which makes the food unfit to eat.

Moulds are plants, with a mass of branching, intertwined, multi-cellular filaments. These form spores, which are very light and coloured. The colour helps to identify the type of mould present. Moulds develop in warm, damp and dark places. Between 25 and 30°C, mould growth is *rapid*. Some mould growth can however, take place at lower temperature, *even* at refrigeration temperatures.

Most moulds are not harmful.

A relatively *small* number of moulds produce toxic materials in food. These toxins are known as *mycotoxins*. *Aflatoxins* are an example of this group. Aflatoxins are produced in harvested crops, such as groundnuts, wheat, millet and rye if these are not dried promptly after harvest and stored.

Yeasts grow usually on foods, such as fruits which have sugar and water. The musty smell of spoiled grapes is due to the growth of yeasts *on them*. Yeasts have usually spherical to ovoid cells and they reproduce by *budding* of these cells. Many yeasts grow best in acid medium and in the presence of ample oxygen. The growth is most rapid between 25°C and 30°C. Foods are often contaminated with yeasts and they can cause spoilage by conversion of the sugar present in the foods to alcohol and carbon dioxide. Foods liable to be spoiled by yeasts are fruit juices, syrups, molasses, honey, jams and jellies.

Bacteria are unicellular organisms and are much smaller in size than either yeasts or moulds. They occur in different sizes and shapes and are classified as coccus (spheroidal), bacilli (cylindrical) or spirillae (spirillar) on the basis of their shape as seen under the microscope. Bacteria vary in their requirements for food, moisture, acidity, temperature and oxygen. Bacteria can grow and develop rapidly between 20°C and 53°C. Bacteria usually cause spoilage in foods, which are neutral in their reaction, such as vegetables, milk, eggs, meat and fish. Some of them when ingested can be harmful to human beings. A few others can produce toxins in foods.

Bacteria that require for their growth:

1. A higher temperature than 45°C are known as *thermophiles*.

2. Temperatures between 20 and 25°C are called *mesophiles*.
3. Temperature less than 20°C are called *psychrophiles*.

Some of them need oxygen for growth (aerobic) and others grow only in the absence of oxygen (anaerobic). Some of them when ingested can be harmful to human beings.

The effect of different temperatures on microorganisms has been depicted in Fig. 16.1.

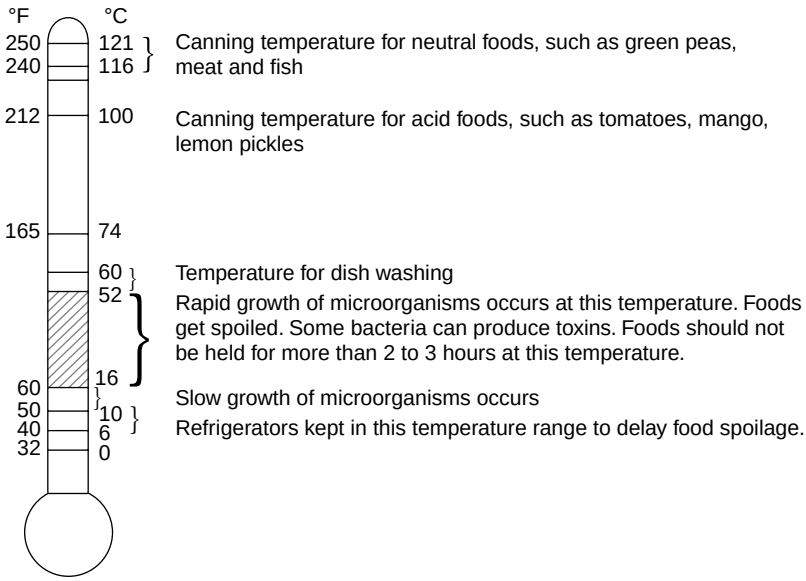

Fig. 16.1 Temperature of Food and Control of Microorganisms

Spoilage by Enzymes

Enzymes are organic catalysts produced by living cells. Many reactions in plant and animal tissues are activated by enzymes. They are proteins and hence are denatured by heat. The changes in foods during storage can be produced both by enzymes present in the food or by enzymes from micro-organisms that contaminate the food. A good example is the ripening of banana in which the enzymes present in the fruit hasten the ripening process. Beyond a certain stage, the enzymes can render the fruit too soft and unfit to eat. If there is a bruised spot in the fruit, yeasts could grow and produce enzymes, which could spoil the fruit. Enzymes can act from 0°C to 60°C. Their optimum temperature of reaction is usually 37°C, their rate of reaction varies directly with temperatures. All enzymes are inactivated by temperatures above 80°C.

Spoilage by Insects

Worms, bugs, weevils, fruit flies, and moths may damage food and reduce its nutrient content and render it unfit for human consumption.

1

Food Preservation: Overview

Mohammad Shafiur Rahman

CONTENTS

1.1 Introduction

Food preservation involves the action taken to maintain foods with the desired properties or nature for as long as possible. The process is now moving from an art to a highly interdisciplinary science. This chapter provides an overview of food preservation methods with emphasis on inactivation, inhibition, and methods of avoiding recontamination. The final section is a discussion of the factors that need to be considered to satisfy present and future demands of the consumers and law-enforcing authorities.

In most countries, innovation, sustainability, and safety have become the main foci of modern industry and economy. The United Nations World Commission on Environment and Development defined sustainable development as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs." A sustainable way of designing and developing food products stands to appeal to consumers, and provides a point of differentiation from competitors and a perfect platform for a range of positive public relations activities [6]. Innovation is vital to maintain progress in technology and engineering. Food safety is now the first priority of the food production and preservation industry, incorporating innovation and sustainability. The industry can compromise with some quantities such as color to some extent, but not with safety.

The preservation and processing of food is not as simple or straightforward as it was in the past. A number of new preservation techniques are being developed to satisfy current demands of economic preservation and consumer satisfaction in nutritional and sensory aspects, convenience, safety, absence of chemical preservatives, price, and environmental safety. Understanding the effects of each preservation method on food has therefore become critical in all aspects. This chapter provides overviews of the new technology, identifying the changing demands of food quality, convenience, and safety.

1.2 What Are Foods?

Foods are materials, raw, processed, or formulated, that are consumed orally by humans or animals for growth, health, satisfaction, pleasure, and satisfying social needs. Generally, there is no limitation on the amount of food that may be consumed (as there is for a drug in the form of dosage) [10]. This does not mean that we can eat any food item as much as we want. Excessive amounts could be lethal, for example, salt, fat, and sugar. Chemically, foods are mainly composed of water, lipids, fat, and carbohydrate with small proportions of minerals and organic compounds. Minerals include salts and organic substances include vitamins, emulsifiers, acids, antioxidants, pigments, polyphenols, and flavor-producing compounds [19]. The different classes of foods are perishable, nonperishable, harvested, fresh, minimally processed, preserved, manufactured, formulated, primary, secondary derivatives, synthetic, functional, and medical foods [21]. The preservation method is mainly based on the types of food that need to be prepared or formulated.

1.3 Food Preservation

Preservation methods start with the complete analysis and understanding of the whole food chain, including growing, harvesting, processing, packaging, and distribution; thus an integrated approach needs to be applied. It lies at the heart of food science and technology, and it is the main purpose of food processing. First, it is important to identify the properties or characteristics that need to be preserved. One property may be important for one product, but detrimental for others. For example, collapse and pore formation occur during the drying of foods. This can be desirable or undesirable depending on the desired quality of the dried product, for example, crust formation is desirable for long bowl life in the case of breakfast cereal ingredients, and quick rehydration is necessary (i.e., no crust and more open pores) for instant soup ingredients. In another instance, the consumer expects apple juice to be clear whereas orange juice could be cloudy.

1.3.1 Why Preservation?

Another important question is *why* food needs to be preserved. The main reasons for food preservation are to overcome inappropriate planning in agriculture, produce value-added products, and provide variation in diet [20]. The agricultural industry produces raw food materials in different sectors. Inadequate management or improper planning in agricultural production can be overcome by avoiding inappropriate areas, times, and amounts of raw food materials as well as by increasing storage life using simple methods of preservation. Value-added food products can give better-quality foods in terms of improved nutritional, functional, convenience, and sensory properties. Consumer demand for healthier and more convenient foods also affects the way food is preserved. Eating should be pleasurable to the consumer, and not boring. People like to eat wide varieties of foods with different tastes and flavors. Variation in the diet is important, particularly in underdeveloped countries to reduce reliance on a specific type of grain (i.e., rice or wheat). In food preservation, the important points that need to be considered are

- The desired level of quality
- The preservation length
- The group for whom the products are preserved

After storage of a preserved food for a certain period, one or more of its quality attributes may reach an undesirable state. Quality is an illusive, ever-changing concept. In general, it is defined as the degree

of fitness for use or the condition indicated by the satisfaction level of consumers. When food has deteriorated to such an extent that it is considered unsuitable for consumption, it is said to have reached the end of its shelf life. In studying the shelf life of foods, it is important to measure the rate of change of a given quality attribute [25]. In all cases, safety is the first attribute, followed by other quality. The product quality attributes can be quite varied, such as appearance, sensory, or microbial characteristics. Loss of quality is highly dependent on types of food and composition, formulation (for manufactured foods), packaging, and storage conditions [25]. Quality loss can be minimized at any stage of food harvesting, processing, distribution, and storage. When preservation fails, the consequences range broadly from minor deterioration, such as color loss, to food becoming extremely hazardous [8].

1.3.2 How Long to Preserve?

After storage for a certain period, one or more quality attributes of a food may reach an undesirable state. At that time, the food is considered unsuitable for consumption and is said to have reached the end of its shelf life. This level is defined by the manufacturer according to criteria when the product is saleable. Best-before date is set shorter than the shelf life with a good margin. Hence, it is usually safe and palatable to consume a product a long time after the best-before date, provided the product has been stored at the recommended conditions. Products may be marketed with the production date "pack date" and "best-before date." Alternative markings are use-by date or expiration date, which may be closer to shelf life than best-before date [1]. In studying the shelf life of foods, it is important to measure the rate of change of a given quality attribute [25]. The product quality can be defined using many factors, including appearance, yield, eating characteristics, and microbial characteristics, but ultimately the final use must provide a pleasurable experience for the consumer [23]. The various stages of food production, manufacture, storage, distribution, and sale are shown in Figure 1.1. Quality loss can be minimized at any stage and thus quality depends on the overall control of the processing chain. The major quality-loss mechanisms and consequences are shown in Table 1.1 and Figure 1.2. The required length of preservation depends on the purpose. In many cases, very prolonged storage or shelf life is not needed, which simplifies both the transport and marketing of the foodstuff. For example, the meals prepared for lunch need a shelf life of only one or even half a day. In this case, there is no point in ensuring preservation of the product for weeks or months. In other cases, very long shelf life up to 3–5 years may be required, for example, foods for space travelers and food storage during wars.

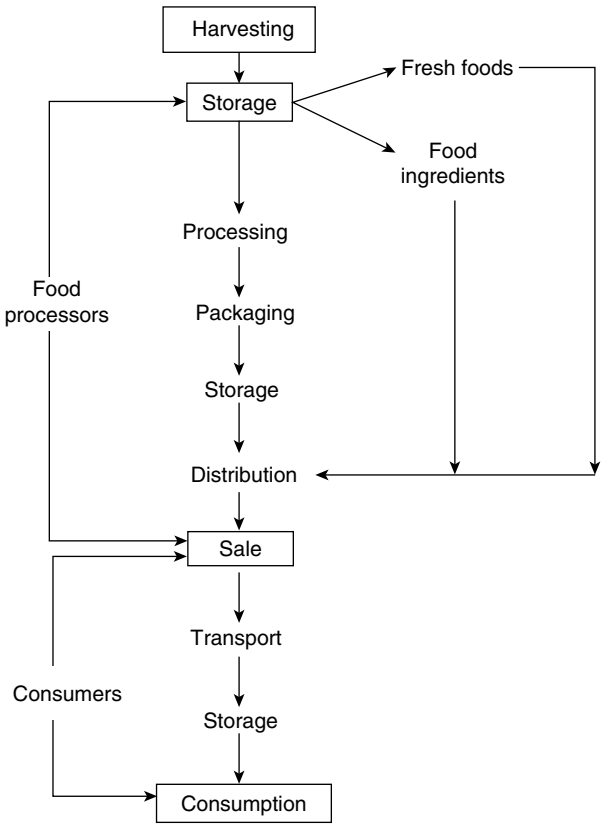

FIGURE 1.1 Various stages of food production, manufacture, storage, distribution, and sale.

1.3.3 For Whom to Preserve?

It is important to know for whom the preserved food is being produced. Nutritional requirements and food restrictions apply differently to different population groups. Food poisoning can be fatal, especially in infants, pregnant women, the elderly, and those with depressed immune systems. The legal aspects of food preservation are different

TABLE 1.1

Major Quality-Loss Mechanisms

Microbiological	Enzymatic	Chemical	Physical	Mechanical
Microorganism growth	Browning	Color loss	Collapse	Bruising due to vibration
Off-flavor	Color change	Flavor loss	Controlled release	Cracking
Toxin production	Off-flavor	Nonenzymatic browning	Crystallization	Damage due to pressure
		Nutrient loss	Flavor encapsulation	
		Oxidation–reduction	Phase changes	
		Rancidity	Recrystallization	
			Shrinkage	
			Transport of component	

Source: Gould, G. W. 1989. In: *Mechanisms of Action of Food Preservation Procedures*. Gould, G. W., Ed. Elsevier Applied Science, London; Gould, G. W. 1995. In: *New Methods of Food Preservation*. Gould, G. W., Ed. Blackie Academic and Professional, Glasgow.

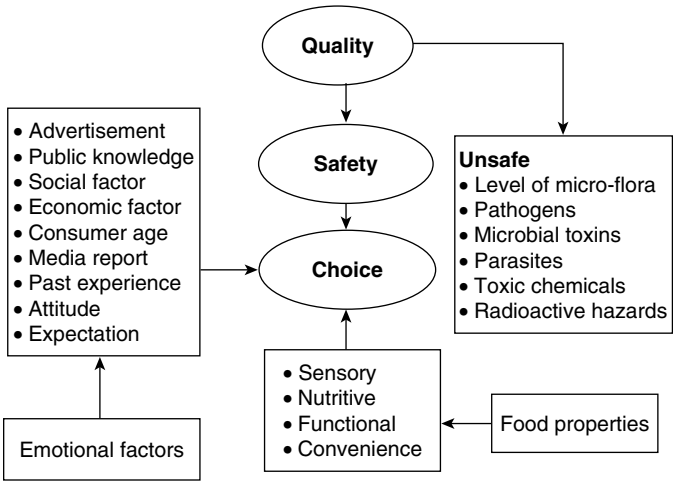

FIGURE 1.2 Factors affecting food quality, safety, and choice.

in case of foods produced for human and for animal consumption. Thus, it is necessary to consider the group for whom the products are being manufactured.

1.4 Causes of Deterioration

Mechanical, physical, chemical, and microbial effects are the leading causes of food deterioration and spoilage. Damage can start at the initial point by mishandling of foods during harvesting, processing, and distribution; this may lead to ultimate reduction of shelf life. Other examples of deterioration can be listed as follows: (i) bruising of fruits and vegetables during harvesting and postharvest handing, leading to the development of rot, (ii) tuberous and leafy vegetables lose water when kept in atmospheres with low humidity and, subsequently, wilt, and (iii) dried foods kept in high humidity may pick up moisture and become soggy. The four sources of microbial contaminants are soil, water, air, and animals (insects, rodents, and humans) (Table 1.2). The major causes of quality loss are shown in Table 1.1. In preservation, each

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Blanching

Blanching serves a variety of functions, one of the main ones being to destroy enzymic activity in vegetables and some fruits, prior to further processing. As such, it is not intended as a sole method of preservation but as a pre-treatment which is normally carried out between the preparation of the raw material (Chapter 3) and later operations (particularly heat sterilisation, dehydration and freezing (Chapters 12, 15 and 21)). Blanching is also combined with peeling and/or cleaning of food (Chapter 3), to achieve savings in energy consumption, space and equipment costs.

A few processed vegetables, for example onions and green peppers, do not require blanching to prevent enzyme activity during storage, but the majority suffer considerable loss in quality if blanching is omitted or if they are under-blanched. To achieve adequate enzyme inactivation, food is heated rapidly to a pre-set temperature, held for a pre-set time and then cooled rapidly to near ambient temperatures. The factors which influence blanching time are:

- type of fruit or vegetable
- size of the pieces of food
- blanching temperature
- method of heating.

10.1 Theory

The theory of unsteady-state heat transfer by conduction and convection, which is used to calculate blanching time, and a sample problem (Sample problem 1.7) are described in Chapter 1.

The maximum processing temperature in freezing and dehydration is insufficient to inactivate enzymes. If the food is not blanched, undesirable changes in sensory characteristics and nutritional properties take place during storage. In canning, the time taken to reach sterilising temperatures, particularly in large cans, may be sufficient to allow enzyme activity to take place. It is therefore necessary to blanch foods prior to

these preservation operations. Under-blanching may cause more damage to food than the absence of blanching does, because heat, which is sufficient to disrupt tissues and release enzymes, but not inactivate them, causes accelerated damage by mixing the enzymes and substrates. In addition, only some enzymes may be destroyed which causes increased activity of others and accelerated deterioration.

The heat resistance of enzymes is characterised by D and z values (Chapter 1). Enzymes which cause a loss of eating and nutritional qualities in vegetables and fruits include lipoxygenase, polyphenoloxidase, polygalacturonase and chlorophyllase. Two heat-resistant enzymes which are found in most vegetables are catalase and peroxidase. Although they do not cause deterioration during storage, they are used as marker enzymes to determine the success of blanching. Peroxidase is the more heat resistant of the two, so the absence of residual peroxidase activity would indicate that other less heat-resistant enzymes are also destroyed. The factors that control the rate of heating at the centre of the product are discussed in Chapter 1 and can be summarised as:

- the temperature of the heating medium
- the convective heat transfer coefficient
- the size and shape of the pieces of food
- the thermal conductivity of the food.

Blanching reduces the numbers of contaminating micro-organisms on the surface of foods and hence assists in subsequent preservation operations. This is particularly important in heat sterilisation (Chapter 12), as the time and temperature of processing are designed to achieve a specified reduction in cell numbers. If blanching is inadequate, a larger number of micro-organisms are present initially and this may result in a larger number of spoiled containers after processing. Freezing and drying do not substantially reduce the number of micro-organisms in unblanched foods and these are able to grow on thawing or rehydration.

Blanching also softens vegetable tissues to facilitate filling into containers and removes air from intercellular spaces which increases the density of food and assists in the formation of a head-space vacuum in cans (Chapters 12 and 25).

10.2 Equipment

The two most widespread commercial methods of blanching involve passing food through an atmosphere of saturated steam or a bath of hot water. Both types of equipment are relatively simple and inexpensive. Microwave blanching is not yet used commercially on a large scale. It is discussed further in Chapter 18. There have been substantial developments to blanchers in recent years to reduce the energy consumption and also to reduce the loss of soluble components of foods, which reduces the volume and polluting potential of effluents (Chapter 26) and increases the yield of product.

The yield[1] of food from the blanching operation is the most important factor in determining the commercial success of a particular method. In some methods the cooling stage may result in greater losses of product or nutrients than the blanching stage, and it is therefore important to consider both blanching and cooling when comparing different methods. Steam blanching results in higher nutrient retention provided that cooling is by cold-air or cold-water sprays. Cooling with running water (fluming) substantially

1. Weight of food after processing compared to the weight before processing.

increases leaching losses,[2] but the product may gain weight by absorbing water and the overall yield is therefore increased. Air cooling causes weight loss of the product due to evaporation, and this may outweigh any advantages gained by nutrient retention (Bomben *et al.*, 1975).

There are also substantial differences in yield and nutrient retention due to differences in the type of food and differences in the method of preparation (for example slicing and peeling (Chapter 3) increase losses and reduce the yield).

Recycling of water does not affect the product quality or yield but substantially reduces the volume of effluent produced. However, it is necessary to ensure adequate hygienic standards for both the product and equipment by preventing a build-up of bacteria in cooling water, and the improved hygiene control may result in additional costs which outweigh savings in energy and higher product yield.

10.2.1 Steam blanchers

The advantages and limitations of steam blanchers are described in Table 10.1. In general this is the preferred method for foods with a large area of cut surfaces as leaching losses are much smaller than those found using hot-water blanchers.

At its simplest a steam blancher consists of a mesh conveyor belt that carries food through a steam atmosphere in a tunnel. The residence time of the food is controlled by the speed of the conveyor and the length of the tunnel. Typically a tunnel is 15 m long and 1–1.5 m wide. The efficiency of energy consumption is 19% when water sprays are used at the inlet and outlet to condense escaping steam. Alternatively, food may enter and leave the blancher through rotary valves or hydrostatic seals to reduce steam losses and increase energy efficiency to 27%, or steam may be re-used by passing through Venturi valves. Energy efficiency is improved to 31% using combined hydrostatic and Venturi devices (Scott *et al.*, 1981).

In conventional steam blanching, there is often poor uniformity of heating in the multiple layers of food. The time–temperature combination required to ensure enzyme inactivation at the centre of the bed results in overheating of food at the edges and a consequent loss of texture and other sensory characteristics. Individual quick blanching

Table 10.1 Advantages and limitations of conventional steam and hot-water blanchers

Equipment	Advantages	Limitations
Conventional steam blanchers	Smaller loss of water-soluble components. Smaller volumes of waste and lower disposal charges than water blanchers, particularly with air cooling instead of water. Easy to clean and sterilise	Limited cleaning of the food so washers also required. Uneven blanching if the food is piled too high on the conveyor. Some loss of mass in the food.
Conventional hot-water blancher	Lower capital cost and better energy efficiency than steam blanchers	Higher costs in purchase of water and charges for treatment of large volumes of dilute effluent (Chapter 26). Risk of contamination by thermophilic bacteria.

2. Washing of soluble components from the food.

11

Pasteurisation

Pasteurisation is a relatively mild heat treatment, in which food is heated to below 100ºC. In low acid foods (pH > 4.5, for example milk) it is used to minimise possible health hazards from pathogenic micro-organisms and to extend the shelf life of foods for several days. In acidic foods (pH < 4.5, for example bottled fruit) it is used to extend the shelf life for several months by destruction of spoilage micro-organisms (yeasts or moulds) and/or enzyme inactivation (Table 11.1). In both types of food, minimal changes are caused to the sensory characteristics or nutritive value.

Processing containers of food, either which have a naturally low pH (for example fruit pieces) or in which the pH is artificially lowered (for example pickles) is similar to canning (Chapter 12). It is often termed *pasteurisation* to indicate the mild heat treatment employed. In this chapter the pasteurisation of liquid foods either packaged in containers or unpackaged, using heat exchangers is described.

11.1 Theory

The sensible heat required to raise the temperature of a liquid during pasteurisation is found using:

$$Q = mc(\theta_A - \theta_B) \qquad 11.1$$

where Q (W) = specific rate of heat transfer, m (kg s^{-1}) = mass flow rate, c (kJ kg^{-1} ºC^{-1}) = specific heat capacity and ($\theta_A - \theta_B$) (ºC) = temperature change. Sample problems of heat transfer during pasteurisation are given in Chapter 1 (Sample problems 1.7 and 1.8) and in Section 11.2.2.

The extent of the heat treatment required to stabilise a food is determined by the D value of the most heat-resistant enzyme or micro-organism which may be present (Chapter 1). For example milk pasteurisation is based on D_{60} and a 12 logarithmic cycle reduction in the numbers of *C. burnetii* (Harper, 1976), and liquid whole egg is treated to produce a 9D reduction in numbers of *S. seftenberg* (Hammid-Samimi and Swartzel, 1984). As flavours, colours and vitamins are also characterised by D values, pasteurisation

Table 11.1 Purpose of pasteurisation for different foods

Food	Main purpose	Subsidiary purpose	Minimum processing conditions[a]
$pH < 4.5$			
Fruit juice	Enzyme inactivation (pectinesterase and polygalacturonase)	Destruction of spoilage micro-organisms (yeasts, fungi)	65ºC for 30 min; 77ºC for 1 min; 88ºC for 15 s
Beer	Destruction of spoilage micro-organisms (wild yeasts, *Lactobacillus* species), and residual yeasts (*Saccharomyces* species)	–	65–68ºC for 20 min (in bottle); 72–75ºC for 1–4 min at 900–1000 kPa
$pH > 4.5$			
Milk	Destruction of pathogens: *Brucella abortis*, *Mycobacterium tuberculosis*, (*Coxiella burnettii*[b])	Destruction of spoilage micro-organisms and enzymes	63ºC for 30 min; 71.5ºC for 15 s
Liquid egg	Destruction of pathogens *Salmonella seftenburg*	Destruction of spoilage micro-organisms	64.4ºC for 2.5 min 60ºC for 3.5 min
Ice cream	Destruction of pathogens	Destruction of spoilage micro-organisms	65ºC for 30 min; 71ºC for 10 min; 80ºC for 15 s

[a] Followed by rapid cooling to 3–7ºC.
[b] Rickettsia organism which causes Q fever.
Adapted from Fricker (1984), Wiggins and Barclay (1984), Lund (1975) and Hammid-Samimi and Swartzel (1984).

conditions can be optimised for retention of nutritional and sensory quality by the use of high-temperature short-time (HTST) conditions. For example in milk processing the lower-temperature longer-time process operating at 63ºC for 30 min (the *holder* process) causes greater changes to flavour and a slightly greater loss of vitamins than HTST processing at 71.8ºC for 15 s (Table 11.2) and it is less often used. Higher temperatures and shorter times (for example 88ºC for 1 s, 94ºC for 0.1 s or 100 ºC for 0.01 s for milk) are described as higher-heat shorter-time processing or 'flash pasteurisation'.

Alkaline phosphatase is a naturally occurring enzyme in raw milk which has a similar *D* value to heat-resistant pathogens (Fig. 11.1). The direct estimation of pathogen numbers by microbiological methods is expensive and time consuming, and a simple test for phosphatase activity is therefore routinely used. If phosphatase activity is found, it is assumed that the heat treatment was inadequate to destroy the pathogenic bacteria or that unpasteurised milk has contaminated the pasteurised product. A similar test for the effectiveness of liquid-egg pasteurisation is based on residual α-amylase activity (Brooks, 1962).

11.2 Equipment

11.2.1 Pasteurisation of packaged foods

Some liquid foods (for example beers and fruit juices) are pasteurised after filling into containers. Hot water is normally used if the food is packaged in glass, to reduce the

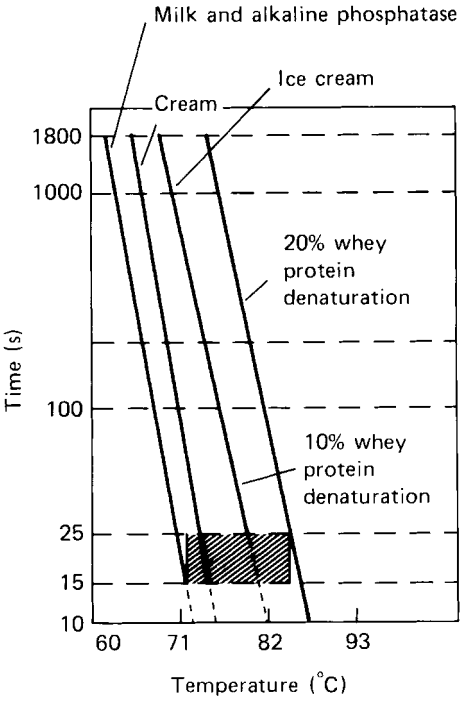

Fig. 11.1 Time–temperature relationships for pasteurisation. The hatched area shows the range of times and temperatures used in commercial milk pasteurisation.
(After Harper (1976).)

risk of thermal shock to the container (fracture caused by rapid changes in temperature). Maximum temperature differences between the container and water are 20ºC for heating and 10ºC for cooling. Metal or plastic containers are processed using steam–air mixtures or hot water as there is little risk of thermal shock. In all cases the food is cooled to approximately 40ºC to evaporate surface water and therefore to minimise external corrosion to the container or cap, and to accelerate setting of label adhesives. Hot-water pasteurisers may be batch or continuous in operation. The simplest batch equipment consists of a water bath in which crates of packaged food are heated to a pre-set temperature and held for the required length of time. Cold water is then pumped in to cool the product. A continuous version consists of a long narrow trough fitted with a conveyor belt to carry containers through heating and cooling stages.

A second design consists of a tunnel divided into a number of heating zones. Very fine (atomised) water sprays heat the containers as they pass through each zone on a conveyor, to give incremental rises in temperature until pasteurisation is achieved. Water sprays then cool the containers as they continue through the tunnel. Savings in energy and water consumption are achieved by recirculation of water between pre-heat sprays, where it is cooled by the incoming food, and cooling zones where it is heated by the hot products (Anon., 1982). Steam tunnels have the advantage of faster heating, giving shorter residence times, and smaller equipment. Temperatures in the heating zones are gradually increased by reducing the amount of air in the steam–air mixtures. Cooling takes place using fine sprays of water or by immersion in a water bath.

11.2.2 Pasteurisation of unpackaged liquids

Swept surface heat exchangers (Barclay *et al.*, 1984) or open boiling pans (Chapter 13) are used for small-scale batch pasteurisation of some liquid foods. However, the large-scale pasteurisation of low viscosity liquids (for example milk, milk products, fruit juices, liquid egg, beers and wines) usually employs plate heat exchangers. Some products (for example fruit juices, wines) also require de-aeration to prevent oxidative changes during storage. They are sprayed into a vacuum chamber and dissolved air is removed by a vacuum pump, prior to pasteurisation.

The *plate heat exchanger* (Fig. 11.2) consists of a series of thin vertical stainless steel plates, held tightly together in a metal frame. The plates form parallel channels, and liquid food and heating medium (hot water or steam) are pumped through alternate channels, usually in a counter-current flow pattern (Fig. 11.3). Each plate is fitted with a synthetic rubber gasket to produce a watertight seal and to prevent mixing of the product

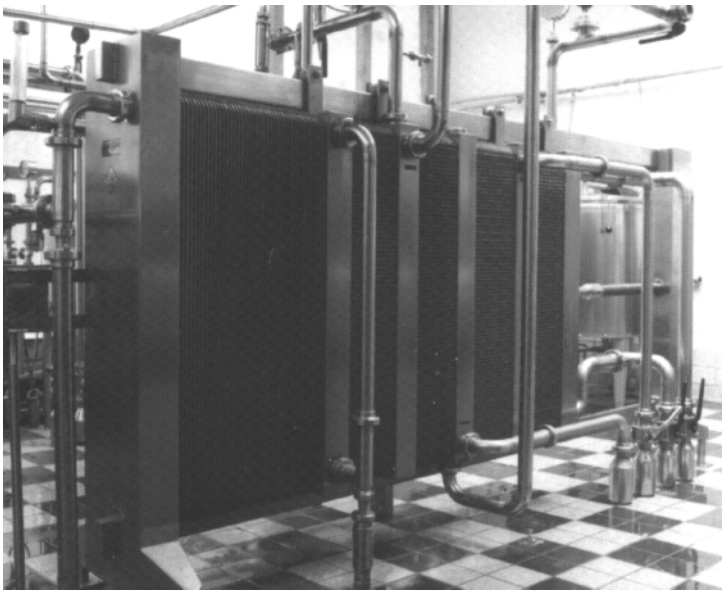

Fig. 11.2 Plate heat exchanger.
(Courtesy of Wincanton Engineering Ltd.)

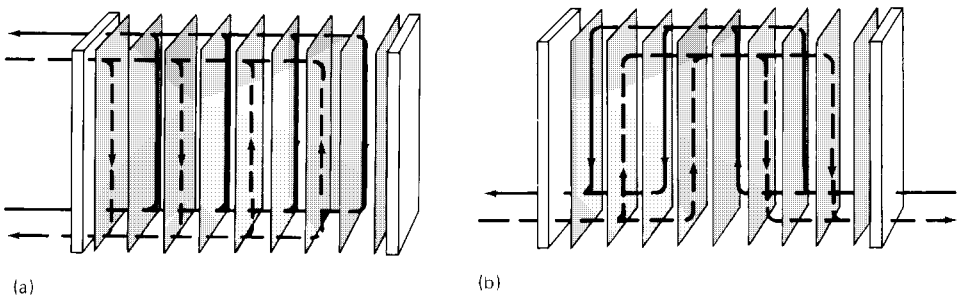

Fig. 11.3 Counter-current flow through plate heat exchanger: (a) one pass with four channels per medium; (b) two passes with two channels per pass and per medium.
(Courtesy of HRS Heat Exchangers Ltd.)

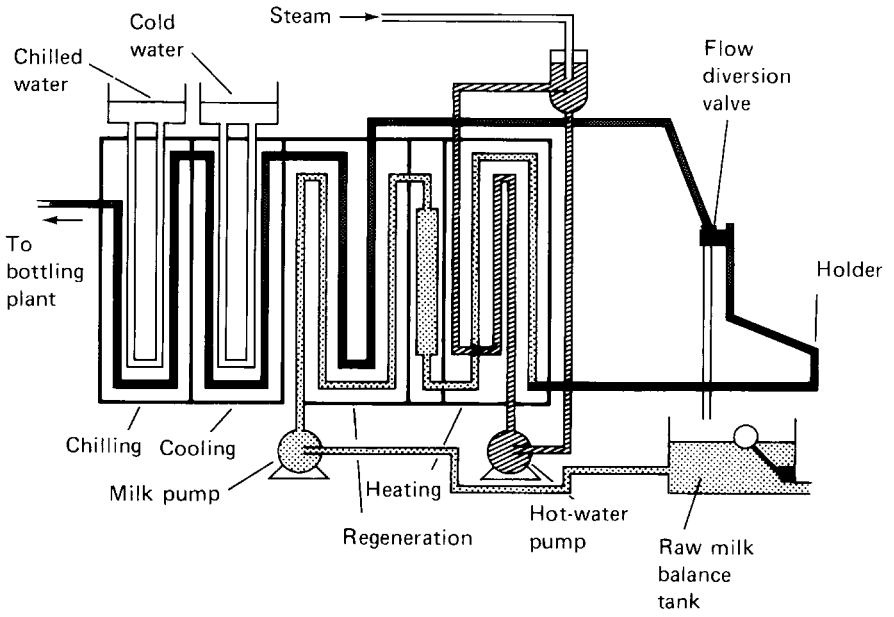

Fig. 11.4 Pasteurising using a plate heat exchanger. (Courtesy of APV Ltd.)

and the heating and cooling media. The plates are corrugated to induce turbulence in the liquids and this, together with the high velocity induced by pumping, reduces the thickness of boundary films (Chapter 1) to give high heat transfer coefficients (3000–11 500 $W\,m^{-2}\,K^{-1}$). The capacity of the equipment varies according to the size and number of plates, up to 80 000 $l\,h^{-1}$.

In operation (Fig. 11.4), food is pumped from a balance tank to a 'regeneration' section, where it is pre-heated by food that has already been pasteurised. It is then heated to pasteurising temperature in a heating section and held for the time required to achieve pasteurisation in a holding tube. If the pasteurising temperature is not reached, a flow diversion valve automatically returns the food to the balance tank to be repasteurised. The pasteurised product is then cooled in the regeneration section (and simultaneously pre-heats incoming food) and then further cooled by cold water and, if necessary, chilled water in a cooling section.

The regeneration of heat in this way leads to substantial savings in energy and up to 97% of the heat can be recovered. Heat recovery is calculated using:

$$\text{heat recovery (\%)} = \frac{\theta_2 - \theta_1}{\theta_3 - \theta_1} \times 100 \qquad 11.2$$

where θ_1 (°C) = inlet temperature, θ_2 (°C) = pre-heating temperature and θ_3 (°C) = pasteurisation temperature.

The advantages of heat exchangers over in-bottle processing include:

- more uniform heat treatment
- simpler equipment and lower maintenance costs
- lower space requirements and labour costs
- greater flexibility for different products
- greater control over pasteurisation conditions.

12

Heat sterilisation

Heat sterilisation is the unit operation in which foods are heated at a sufficiently high temperature and for a sufficiently long time to destroy microbial and enzyme activity. As a result, sterilised foods have a shelf life in excess of six months at ambient temperatures. The severe heat treatment during the older process of in-container sterilisation (canning) may produce substantial changes in nutritional and sensory qualities of foods. Developments in processing technology therefore aim to reduce the damage to nutrients and sensory components, by either reducing the time of processing in containers or processing foods before packaging (aseptic processing). More recent developments, including ohmic heating, are described in Chapter 18. The theory of thermal destruction of micro-organisms and the effect of heat on nutrients and sensory components of foods is described in Chapter 1. In this chapter the effects of microbial heat resistance on the design of heat sterilisation procedures and equipment are described, first for in-container heat sterilisation and then for ultra high-temperature (UHT) processes.

12.1 In-container sterilisation

12.1.1 Theory

The length of time required to sterilise a food is influenced by:

- the heat resistance of micro-organisms or enzymes likely to be present in the food
- the heating conditions
- the pH of the food
- the size of the container
- the physical state of the food.

In order to determine the process time for a given food, it is necessary to have information about both the heat resistance of micro-organisms, particularly heat resistant spores, or enzymes that are likely to be present and the rate of heat penetration into the food.

Heat resistance of micro-organisms

The factors that influence heat resistance of micro-organisms or enzymes and their characterisation by D and z values are described in Chapter 1 (Section 1.4.5). Most heat resistant spores have a z value of around 10ºC. This temperature rise will result in a ten-fold reduction in processing time needed to achieve the same lethality. In low-acid foods (pH > 4.5), the heat resistant, spore forming micro-organism, *Clostridium botulinum* is the most dangerous pathogen likely to be present. Under anaerobic conditions inside a sealed container it can grow to produce a powerful exotoxin, botulin, which is sufficiently potent to be 65% fatal to humans. *Cl. botulinum* is ubiquitous in soil and it is therefore likely to be found in small numbers on any raw material that has contact with soil. Because of the extreme hazard from botulin, the destruction of this micro-organism is therefore a *minimum* requirement of heat sterilisation. Normally, foods receive more than this minimum treatment as other more heat-resistant spoilage bacteria may also be present (Table 12.1). In more acidic foods (pH 4.5–3.7), other micro-organisms (for example yeasts and fungi) or heat-resistant enzymes are used to establish processing times and temperatures. In acidic foods (pH < 3.7), enzyme inactivation is the main reason for processing and heating conditions are less severe (sometimes referred to as *pasteurisation*).

Thermal destruction of micro-organisms takes place logarithmically (Chapter 1) and a sterile product cannot therefore be produced with certainty no matter how long the process time. However, the *probability* of survival of a single micro-organism can be predicted using details of the heat resistance of the micro-organism and the temperature and time of heating. This gives rise to a concept known as *commercial sterility*. For example, a process that reduces cell numbers by twelve decimal reductions (a 12D process), applied to a raw material which contains 1000 spores per container would reduce microbial numbers to 10^{-9} per container, or the probability of one microbial spore surviving in one billion containers processed. Commercial sterility means in practice that

Table 12.1 Heat resistance of some spore-forming bacteria[a] used as a basis for heat sterilisation of low acid foods

Micro-organism	z value (ºC)	D_{121} value (min)	Typical foods
Thermophilic (35–55ºC)			
Bacillus stearothermophilus	9–10	3.0–4.0	Vegetables, milk
Clostridium thermosaccharolyticum	7.2–10	3.0–4.0	Vegetables
Mesophilic (10–40ºC)			
Clostridium sporogenes	8.8–11.1	0.7–1.5	Meats
Bacillus subtilis	4.1–7.2	0.3–0.76	Milk products
Cl. botulinum toxins A and B	5.5	0.1–0.3	Low-acid foods
B. coagulans	6–9	0.01–0.07	Milk
B. cereus	36	3.8	Milk
Psychrophilic (−5−1.5ºC)	10	3.0 (60ºC)	Low-acid foods
Cl. botulinum toxin E			

[a] Note: the data is intended to be indicative only as the thermal resistance of micro-organisms is influenced by the nature of the food. Original literature gives precise information for particular products.
Adapted from Lund (1975), Burton (1988), Brennan *et al.* (1990), Heldman and Hartel (1997) and Licciardello *et al.* (1967).

the heat processing inactivates substantially all micro-organisms and spores which, if present, would be capable of growing in the food under defined storage conditions (Brennan *et al*., 1990).

The level of survival is determined by the type of micro-organism that is expected to contaminate the raw material. A 12*D* process is used when *C. botulinum* is likely to be present in low acid foods, but in foods that contain more heat-resistant spoilage micro-organisms (Table 12.1), the application of a 12*D* process would result in over-processing and excessive loss of quality. In practice a 2*D* to 8*D* process is therefore used to give the most economical level of food spoilage consistent with adequate food quality and safety. However, because of the lower heat resistance of *C. botulinum*, the probability of survival remains similar to that obtained in a 12*D* process. For these processes to operate successfully, the microbial load on raw materials must be kept at a low level by hygienic handling and preparation procedures (Chapter 3), and in some foods by blanching (Chapter 10). Any failure in these procedures would increase the initial numbers of cells and, because of the logarithmic rate of destruction, would increase the incidence of spoilage after processing. In canning factories, accelerated storage trials on randomly selected cans of food ensure that these levels of commercial sterility are maintained before foods are released for retail sale. When *Cl. botulinum* grows and produces toxin in a sealed container there is characteristic production of gas which can cause visible swelling of the container (although this is not the only cause of swelling). Routine quality assurance measures therefore include observation for swollen or bloated cans.

In addition to information on heat resistance, it is necessary to collect data describing the rate of heat penetration into the food in order to calculate the processing time needed for commercial sterility.

Rate of heat penetration

Heat is transferred from steam or pressurised water through the container and into the food. Generally the surface heat transfer coefficient (Chapter 1) is very high and is not a limiting factor in heat transfer. The following factors are important influences on the rate of heat penetration into a food:

- *Type of product*. Liquid or particulate foods (for example peas in brine) in which natural convection currents are established heat faster than solid foods in which heat is transferred by conduction (for example meat pastes and corned beef) (Fig. 12.1). The low thermal conductivity of foods is a major limitation to heat transfer in conduction heating foods.
- *Size of the container*. Heat penetration to the centre is faster in small containers than in large containers.
- *Agitation of the container*. End-over-end agitation (Fig. 12.2) and, to a lesser extent, axial agitation increases the effectiveness of natural convection currents and thereby increases the rate of heat penetration in viscous or semi-solid foods (for example beans in tomato sauce).
- *Temperature of the retort*. A higher temperature difference between the food and the heating medium causes faster heat penetration.
- *Shape of the container*. Tall containers promote convection currents in convective heating foods.
- *Type of container*. Heat penetration is faster through metal than through glass or plastics owing to differences in their thermal conductivity (Table 1.5).

13

Evaporation and distillation

In common with other unit operations that are intended to separate components of foods (Chapter 6), evaporation and distillation aim to separate specific components to increase the value of the food. In both types of operation, separation is achieved by exploiting differences in the vapour pressure (volatility) of the components and using heat to remove one or more from the bulk of the food.

13.1 Evaporation

Evaporation, or concentration by boiling, is the partial removal of water from liquid foods by boiling off water vapour. It increases the solids content of a food and hence preserves it by a reduction in water activity (Chapter 1). Evaporation is used to pre-concentrate foods (for example fruit juice, milk and coffee) prior to drying, freezing or sterilisation and hence to reduce their weight and volume. This saves energy in subsequent operations and reduces storage, transport and distribution costs. There is also greater convenience for the consumer (for example fruit drinks for dilution, concentrated soups, tomato or garlic pastes, sugar) or for the manufacturer (for example liquid pectin, fruit concentrates for use in ice cream or baked goods). Changes to food quality that result from the relatively severe heat treatment are minimised by the design and operation of the equipment. Evaporation is more expensive in energy consumption than other methods of concentration (membrane concentration (Chapter 6)) and freeze concentration (Chapter 22) but a higher degree of concentration can be achieved (Table 13.1).

13.1.1 Theory

During evaporation, sensible heat is transferred from steam to the food, to raise the temperature to its boiling point. Latent heat of vaporisation is then supplied by the steam to form bubbles of vapour, which leave the surface of the boiling liquid. The rate of evaporation is determined by both the rate of heat transfer into the food and the rate of

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Dehydration

Dehydration (or drying) is defined as 'the application of heat under controlled conditions to remove the majority of the water normally present in a food by evaporation' (or in the case of freeze drying (Chapter 22) by sublimation). This definition excludes other unit operations which remove water from foods (for example mechanical separations and membrane concentration (Chapter 6), evaporation (Chapter 13) and baking (Chapter 16)) as these normally remove much less water than dehydration.

The main purpose of dehydration is to extend the shelf life of foods by a reduction in water activity (Chapter 1). This inhibits microbial growth and enzyme activity, but the processing temperature is usually insufficient to cause their inactivation. Therefore any increase in moisture content during storage, for example due to faulty packaging, will result in rapid spoilage. The reduction in weight and bulk of food reduces transport and storage costs. For some types of food, dehydration provides a convenient product for the consumer or more easily handled ingredients for food processors. Drying causes deterioration of both the eating quality and the nutritional value of the food. The design and operation of dehydration equipment aim to minimise these changes by selection of appropriate drying conditions for individual foods. Examples of commercially important dried foods are coffee, milk, raisins, sultanas and other fruits, pasta, flours (including bakery mixes), beans, pulses, nuts, breakfast cereals, tea and spices. Examples of important dried ingredients that are used by manufacturers include egg powder, flavourings and colourings, lactose, sucrose or fructose powder, enzymes and yeasts.

15.1 Theory

Dehydration involves the simultaneous application of heat and removal of moisture from foods.[1] Factors that control the rates of heat and mass transfer are described in Chapter 1.

1. Except for osmotic dehydration, in which foods are soaked in concentrated solutions of sugar or salt to remove water using the difference in osmotic pressure as the driving force for moisture transfer. This method is used to produce 'crystallised' or sugared fruits and with salt it is used in some countries as a pre-treatment for fish and vegetables before drying. Further details are given by Torreggiani (1993).

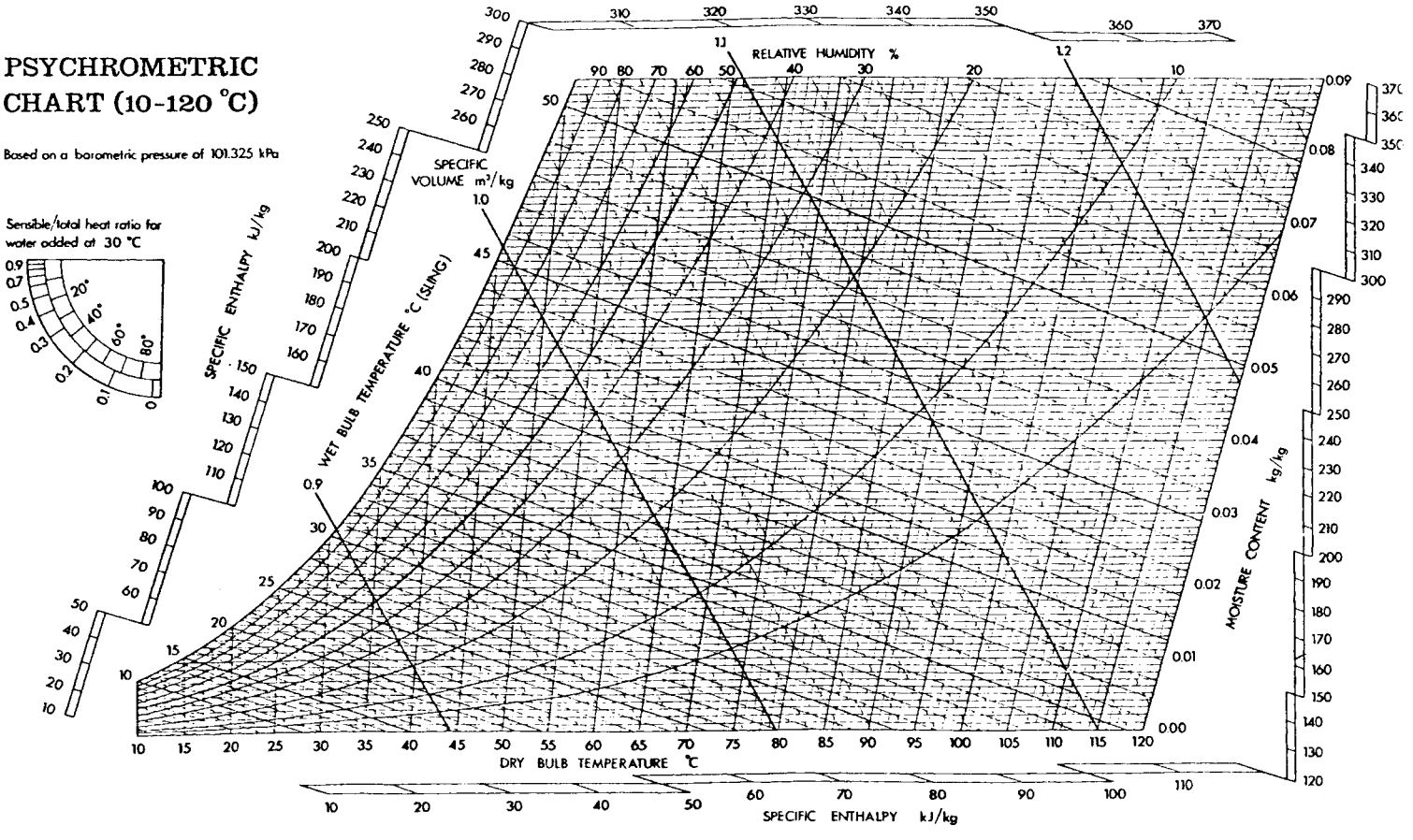

Fig. 15.1 Psychrometric chart (10–120ºC) based on barometric pressure of 101.325 kPa. (Courtesy of Chartered Institution of Building Service Engineers.)

Dehydration by heated air or heated surfaces is described in this chapter. Microwave, dielectric and radiant driers are described in Chapter 18 and freeze drying is described in Chapter 22.

There are a large number of factors that control the rate at which foods dry, which can be grouped into the following categories:

- those related to the processing conditions
- those related to the nature of the food
- those related to the drier design.

The effects of processing conditions and type of food are described below and differences in drier design are summarised in Section 15.2.

15.1.1 Drying using heated air

Psychrometrics

There are three inter-related factors that control the capacity of air to remove moisture from a food:

1. the amount of water vapour already carried by the air
2. the air temperature
3. the amount of air that passes over the food.

The amount of water vapour in air is expressed as either *absolute humidity*[2] (termed *moisture content* in Fig. 15.1) or *relative humidity*[3] (RH) (in per cent). Psychrometry is the study of inter-related properties of air–water vapour systems. These properties are conveniently represented on a *psychrometric chart* (Fig. 15.1).

Heat from drying air is absorbed by food and provides the latent heat needed to evaporate water from the surface. The temperature of the air, measured by a thermometer bulb, is termed the *dry-bulb* temperature. If the thermometer bulb is surrounded by a wet cloth, heat is removed by evaporation of water from the cloth and the temperature falls. This lower temperature is called the *wet-bulb temperature*. The difference between the two temperatures is used to find the relative humidity of air on the psychrometric chart. An increase in air temperature, or reduction in RH, causes water to evaporate more rapidly from a wet surface and therefore produces a greater fall in temperature. The *dew point* is the temperature at which air becomes saturated with moisture (100% RH) and any further cooling from this point results in condensation of the water from the air. Adiabatic cooling lines are the parallel straight lines sloping across the chart, which show how absolute humidity decreases as the air temperature increases.

Mechanism of drying

The third factor that controls the rate of drying, in addition to air temperature and humidity, is the air velocity. When hot air is blown over a wet food, water vapour diffuses through a boundary film of air surrounding the food and is carried away by the moving air (Fig. 15.2). A water vapour pressure gradient is established from the moist interior of the food to the dry air. This gradient provides the ‘driving force’ for water removal from the food.

2. Equals the mass of water vapour per unit mass of dry air (in kilograms per kilogram).
3. Defined as ‘the ratio of the partial pressure of water vapour in the air to the pressure of saturated water vapour at the same temperature, multiplied by 100’.

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Chilling

Chilling is the unit operation in which the temperature of a food is reduced to between −1ºC and 8ºC. It is used to reduce the rate of biochemical and microbiological changes, and hence to extend the shelf life of fresh and processed foods. It causes minimal changes to sensory characteristics and nutritional properties of foods and, as a result, chilled foods are perceived by consumers as being convenient, easy to prepare, high quality and 'healthy', 'natural' and 'fresh'. Since the 1980s there has been substantial product development and strong growth in the chilled food market, particularly for sandwiches, desserts, ready meals, prepared salads, pizza and fresh pasta (Jennings, 1997). Bond (1992), for example, describes the introduction of 1000 new chilled products *per annum* in the late 1980s, with product development still continuing at a rate of some 750 new products per year.

Chilling is often used in combination with other unit operations (for example fermentation (Chapter 7) or pasteurisation (Chapter 11)) to extend the shelf life of mildly processed foods. There is a greater preservative effect when chilling is combined with control of the composition of the storage atmosphere (Chapter 20) than that found using either unit operation alone. However, not all foods can be chilled and tropical, subtropical and some temperate fruits, for example, suffer from chilling injury at 3–10ºC above their freezing point.

Chilled foods are grouped into three categories according to their storage temperature range as follows (Hendley, 1985):

1. −1ºC to +1ºC (fresh fish, meats, sausages and ground meats, smoked meats and breaded fish).
2. 0ºC to +5ºC (pasteurised canned meat, milk, cream, yoghurt, prepared salads, sandwiches, baked goods, fresh pasta, fresh soups and sauces, pizzas, pastries and unbaked dough).
3. 0ºC to +8ºC (fully cooked meats and fish pies, cooked or uncooked cured meats, butter, margarine, hard cheese, cooked rice, fruit juices and soft fruits).

Details of the range of available chilled foods and future trends are given by Bond (1992) and Dade (1992).

The successful supply of chilled foods to the consumer is heavily dependent on sophisticated and relatively expensive distribution systems which involve chill stores, refrigerated transport and retail chill display cabinets, together with widespread ownership of domestic refrigerators. Precise temperature control is essential at all stages to avoid the risk of food spoilage or food poisoning. In particular, low-acid chilled foods, which are susceptible to contamination by pathogenic bacteria (for example fresh and pre-cooked meats, pizzas and unbaked dough) must be prepared, packaged and stored under strict conditions of hygiene and temperature control. Details of legislation that affects temperature control of chilled foods in Europe and North America are given by Turner (1992) and Woolfe (2000).

19.1 Theory

19.1.1 Fresh foods

The rate of biochemical changes caused by either micro-organisms or naturally occurring enzymes increases logarithmically with temperature (Chapter 1). Chilling therefore reduces the rate of enzymic and microbiological change and retards respiration of fresh foods. The factors that control the shelf life of fresh crops in chill storage include:

- the type of food and variety or cultivar
- the part of the crop selected (the fastest growing parts have the highest metabolic rates and the shortest storage lives (Table 19.1))
- the condition of the food at harvest (for example the presence of mechanical damage or microbial contamination, and the degree of maturity)
- the temperature of harvest, storage, distribution and retail display
- the relative humidity of the storage atmosphere, which influences dehydration losses.

Further details are given in Section 19.3.

The rate of respiration of fresh fruits is not necessarily constant at a constant storage temperature. Fruits which undergo 'climacteric' ripening show a short but abrupt increase in the rate of respiration which occurs near to the point of optimum ripeness.

Table 19.1 Botanical function related to respiration rate and storage life for selected products

Product	Relative respiration rate	Botanical function	Typical storage life (weeks at 2ºC)
Asparagus	40	Actively growing shoots	0.2–0.5
Mushrooms	21		
Artichokes	17		
Spinach	13	Aerial parts of plants	1–2
Lettuce	11		
Cabbage	6		
Carrots	5	Storage roots	5–20
Turnips	4		
Beetroots	3		
Potatoes	2	Specialised storage organs	25–50
Garlic	2		
Onions	1		

From Alvarez and Thorne (1981).

Table 19.2 Heat produced by respiration in selected foods

Food	Heat (W t^{-1}) of respiration for the following storage temperatures		
	0ºC	10ºC	15.5ºC
Apples	10–12	41–61	58–87
Bananas	–	65–116	–
Beans	73–82	–	440–580
Carrots	46	93	–
Celery	21	58–81	–
Oranges	9–12	35–40	68
Lettuce	150	–	620
Pears	8–20	23–63	–
Potatoes	–	20–30	–
Strawberries	36–52	145–280	510
Tomatoes	57–75	–	78

Adapted from Leniger and Beverloo (1975) and Lewis (1990).

Climacteric fruits include apple, apricot, avocado, banana, mango, peach, pear, plum and tomato. Non-climacteric fruits include cherry, cucumber, fig, grape, grapefruit, lemon, pineapple and strawberry. Vegetables respire in a similar way to non-climacteric fruits. Differences in respiratory activity of selected fruits and vegetables are shown in Tables 19.1 and 19.2.

Undesirable changes to some fruits and vegetables occur when the temperature is reduced below a specific optimum for the individual fruit. This is termed *chilling injury* and results in various physiological changes (for example internal or external browning, failure to ripen and skin blemishes). The reasons for this are not fully understood but may include an imbalance in metabolic activity which results in the over-production of metabolites that then become toxic to the tissues (Haard and Chism, 1996). It is found for example in apples (less than 2–3ºC), avocados (less than 13ºC), bananas (less than 12–13ºC), lemons (less than 14ºC), mangoes (less than 10–13ºC) and melons, pineapples and tomatoes (each less than 7–10ºC). The optimum storage temperature and relative humidity, and expected storage times are shown in Table 19.3 for a variety of fresh fruits and vegetables. Undesirable changes due to incorrect relative humidity are described by van den Berg and Lentz (1974).

In animal tissues, aerobic respiration rapidly declines when the supply of oxygenated blood is stopped at slaughter. Anaerobic respiration of glycogen to lactic acid then causes the pH of the meat to fall, and the onset of *rigor mortis*, in which the muscle tissue becomes firm and inextensible. Cooling during anaerobic respiration is necessary to produce the required texture and colour of meat and to reduce bacterial contamination. Undesirable changes, caused by cooling meat before rigor mortis has occurred, are termed *cold shortening*. Details of these and other post-mortem changes to meat are described by Laurie (1998).

To chill fresh foods it is necessary to remove both sensible heat (also known as *field heat*) and heat generated by respiratory activity. The production of respiratory heat at 20ºC and atmospheric pressure is given by equation (19.1).

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2.835 \times 10^6 \text{J kmol}^{-1} C_6H_{12}O_6 \qquad 19.1$$

The size of refrigeration plant and the processing time required to chill a crop are calculated using unsteady-state heat transfer methods (Chapter 1). The calculations are

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Food Additives

Up until about 1906, food handled in the United States was often produced and processed under unsafe and unsanitary conditions and there was little control over chemical additives used as preservatives or colorings. In 1906, Upton Sinclair published his book entitled *The Jungle*, which was based upon the meat-packing industry in Chicago. In the book, Sinclair intended to focus on poor working conditions and exploitation of workers, but his description of how meat products were handled led to the passage of the Meat Inspection Act of 1907 and the Federal Food and Drug Act of 1906. At that time, it was quite common to have floor sweepings added to pepper, ash leaves to tea, brick dust to cocoa, copper salts to pickles and peas, and lead salts to candy. Approximately 80 different dyes were used in foods, and sometimes the same batch used for coloring textiles was used for coloring food.

In 1903, Dr. Harvey Washington Wiley, then the Chief of Bureau of Chemistry of the U.S. Department of Agriculture, established a "poison squad" that consisted of young men who consumed foods treated with known amounts of chemicals commonly used in foods. The goal of the project was to determine whether these compounds were deleterious to health. The result of the efforts of Dr. Wiley and the "squad" was the passage of the Food and Drug Act of 1906, which is also referred to as "The Pure Food Act."

The Bureau of Chemistry was the enforcement agency of the 1906 Act until 1927, when research and enforcement functions were separated and the Food, Drug and Insecticide Administration was established. The name of this organization was changed to the Food and Drug Administration (FDA) in 1931, and in 1940 it became a unit of the Department of Health and Human Services. In 1938, the Food, Drug and Cosmetic Act (FD&C Act) was passed into law. This Act gave the government authority to conduct on-site inspections and provide for the establishment of standards of identity for individual food products. The Act also allowed the government to obtain federal court injunctions against violators.

Food additives have been defined as chemical substances deliberately added to foods, directly or indirectly, in known and regulated quantities, for purposes of assisting in the processing of foods; preservation of foods; or in improving the flavor, texture, or appearance of foods.

In September of 1958, the FD&C Act was amended to prohibit the use of food additives that had not been adequately tested to establish their safety. The term food additive was defined as follows:

> . . . any substance the intended use of which results or may reasonably be expected to result, directly or indirectly, in its becoming a component or otherwise affecting the characteristics of any food (including any substance intended for use in

> producing, preparing, treating, packaging, transporting or holding food; and including any source of radiation intended for any such use), if such substance is not generally recognized among experts qualified by scientific training and experience to evaluate its safety, as having been adequately shown through scientific procedures (or in the case of a substance used in food prior to January 1, 1958, through either scientific procedures, or experience based on common use in food) to be safe under the conditions of its intended use . . .

An additive may be reactive or inactive; it may be nutritive or nonnutritive; it should be neither toxic nor hazardous. Some substances, such as pesticides, are added to foods unintentionally, and these are, of course, undesirable, and may be hazardous to health. Because of their toxicity, their presence is closely regulated by strict government tolerance guidelines. The Environmental Protection Agency (EPA), established in 1970, is responsible for establishing tolerances for pesticides and the FDA is responsible for monitoring and ensuring compliance to these tolerances for agricultural commodities.

As a result of the Food Additives Amendment of 1958, the term "Generally Recognized as Safe" (GRAS) evolved. Additives are classified as GRAS when they have been used without apparent harm for long periods of time, long before regulations had been put into effect. These include substances such as baking powder chemicals (e.g., sodium bicarbonate), fruit acids such as citric and malic, and gums such as agar-agar. The purpose of this list was to recognize the safety of basic substances without complicated safety testing.

To get new food additives approved, a petition must be submitted to FDA that contains scientific data that clearly show that the intended chemical is harmless in the intended food application at the intended use level. The burden of proving the safety of the additive lies with the company that wishes to use or sell the chemical. This testing can often require several years because the FDA often requires that the additive undergo at least a 2-year feeding study in two species of animals. These studies must reveal both long-term and short-term effects.

A very controversial clause was included in the Food, Drug and Cosmetic Act. A portion of it stated that:

> ". . . no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal."

This clause, known as the Delaney Clause or Amendment, is named after Representative James Delaney of New York, who introduced it into the legislation. It essentially states that if the additive, at any level, can produce cancer in humans or animals or can be shown to be carcinogenic by any other appropriate test, it will not be allowed. This has been a very controversial clause because, although it was added to ensure safety, some additives may cause cancer in some species of animal when fed at levels that would not be possible for humans to ingest under normal food consumption. The use of informed scientific judgment in regulatory decisions may result in a modification of the Delaney Clause in the future.

Ionization radiation is considered an additive because the treatment may induce changes in food. In this case, the FDA tests foods that have been irradiated and approves irradiation sources and maximum dosages.

Besides the requirements mentioned, food additives must also meet five general criteria:

1. Intentional additives must perform their intended function.
2. Additives must not deceive the consumer or conceal faulty ingredients or defects in manufacturing practices.
3. Additives cannot considerably reduce the food's nutritional value.
4. An additive cannot be used to achieve an effect that could be gained by good manufacturing practices.
5. A method of analysis must exist to monitor the use of the additive in foods or its incidental occurrence in foods (such as migration from a packaging material).

PHILOSOPHY OF FOOD ADDITIVES

Foods are made entirely of substances that, in the pure form, can be described as chemicals or chemical compounds. It is important to note that our knowledge of the composition of foods, because of its complexity, is by no means complete. For instance, it is reported that one of the most important of our natural foods, human milk, contains several hundred chemical compounds.

Unfortunately, the interpretation of the word *chemical* is too often inaccurate. Thus, some consumers are apprehensive about purchasing a food that is preserved by treating it with a chemical with which they are unfamiliar. However, a number of foods may be preserved with table salt, which is a chemical. Consumers are not apprehensive about using salt as a preservative, because they are familiar with it, at least for adding taste and sometimes for bringing out the flavor in foods, yet table salt is definitely a chemical, with the name sodium chloride, and the formula NaCl. Refined sugar, vinegar, spices, and other substances that are routinely added to foods are also chemicals or mixtures of chemicals, and the use of these is not questioned. The characteristics of chemicals that we use with confidence are familiarity and frequent use. The characteristics of chemicals that arouse skepticism in consumers are that they are uncommon and unfamiliar.

A large number of chemical additives are unfamiliar, and there is a need for regulatory agencies to question their use from the standpoint of safety. Obviously then, we should not fear the use of chemicals, but we do need to screen them for safety when their effects on human health are not known. Some lessons have been learned along these lines. For example, indiscreet use of certain additives for coloring candy and popcorn was reported to have caused diarrhea in children, resulting in the removal of these dyes from the FDA approved list of additives. There are a number of related concepts that must be remembered when dealing with food additives:

- All foods are composed of chemical compounds, many of which can be extracted and added to other foods, in which case they are classified as additives.
- Any additive or chemical compound can be injurious to health when particularly high levels of that compound are added to foods.
- Any additive or chemical compound can be safe to use when particularly low levels of that compound are added to foods.
- It is necessary to evaluate each additive for usefulness and toxicity in a sensible, scientific way, regardless of how safe its proponents say it is and how toxic its opponents say it is.

The use of radiation for preserving foods has been declared an additive, and whether or not it should be approved by the FDA makes it the prime example of extreme opposition and extreme favor. Quite often, the tendency to take a strong position for the use of an additive might make a proponent rationalize or overlook undesirable investigative scientific data concerning the additive. On the other hand, opponents tend to make irrational demands of investigators to prove the safety of an additive; for example, opponents of the use of radiation for preserving foods have suggested that radiation should not be approved for preserving foods until all possible chemical effects of the process have been identified. This, without going into detail, is an impossible task. It would be just as impossible to identify all the chemical effects of frying foods and of baking food.

Given present capabilities, our most reasonable evaluation of an additive for safety can be made through conventional animal feeding studies. The overall physiological effects that an additive may have on animals of two or three different species over a specified number of generations is the most comprehensive, as well as the most reliable, way to evaluate the safety of a food additive.

It should be remembered that chemical materials cannot be added to foods unless their use, in the quantities added, has been approved by the FDA. Moreover, additives are tested for toxicity in concentrations much greater than those allowed in foods. It should also be remembered that most food additives are components of natural foods and that without these additives the quality of many foods would be greatly inferior to that to which we have become accustomed. The shelf-life or availability of many foods would also be greatly limited were all additives to be eliminated from foods. Food additives are difficult to classify mainly because they overlap each other in numerous combinations of effects. It should be remembered, therefore, that the following classifications are not precise.

Food additives may be used for a number of reasons. At present, over 3000 intentional additives are allowed and they can be divided into several major groups. In this chapter, the major groups are covered and representative additives from each group are mentioned. No attempt is made to cover every food additive that exists.

ANTIOXIDANTS

Antioxidants are food additives used, since about 1947, to stabilize foods that by their composition would otherwise undergo significant loss in quality in the presence of oxygen. Oxidative quality changes in foods include: (1) the development of rancidity from the oxidation of unsaturated fats resulting in off-odors and off-flavors and (2) discoloration from oxidation of pigments or other components of the food.

There is a large number of antioxidants, and although they may function in different ways, the purpose of each is to prevent, delay, or minimize the oxidation of the food to which they are added. One of the ways by which some antioxidants function involves their combination with oxygen. Others prevent oxygen from reacting with components of the food. When only a limited amount of oxygen is present, as in a hermetically sealed container, it is possible for some antioxidants to use up all of the available free oxygen, because they have a relatively great affinity for it. Some antioxidants lose their effectiveness when they combine with oxygen; therefore, there is no advantage to using this type of antioxidant unless the food is enclosed in a system from which oxygen or air can be excluded. With the use of antioxidants, it should be noted that

other precautions are necessary to minimize oxidation, because heat, light, and metals are prooxidants, that is, their presence favors oxidative reactions. Many of the antioxidants used commercially occur naturally in foods (e.g., vitamin C, vitamin E, citric acid, amines, and certain phenolic compounds). However, the amines and the phenolic compounds can be toxic to humans in low concentrations; therefore their use and that of synthetic antioxidants require strict regulation. It should be pointed out that the potency of the naturally occurring antioxidants is not as great as that of the commonly used synthetic antioxidants. The antioxidants that are considered to be the most effective and therefore are most widely used are butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and propylgallate. These are generally used in formulations that contain combinations of two or all three of them, and often in combination with a fourth component, frequently citric acid. The main purpose of adding citric acid is that it serves as a chelator or sequestrant (a chelator ties up metals, thereby preventing metal catalysis of oxidative reactions).

Fats and shortenings, especially those used in bakery goods and fried foods, are subject to oxidation and the development of rancidity after cooking. To prevent this, chemical antioxidants in concentrations up to 0.02% of the weight of the fat component may be added.

The use of antioxidants is regulated by the FDA and is subject to other regulations, such as the Meat Inspection Act and the Poultry Inspection Act. Their use is limited so that the maximum amount that can be added is generally 0.02% of the fat content of the food; however, there are some exceptions to, and variations of, that rule.

NUTRIENT ADDITIVES

The need for a balanced and ample nutrient intake by the human body is well known. Although nutrients are available in foods, losses of fractional amounts of some of them through processing and increasing frequency of improper dieting have led to the practice of adding minimum daily requirements or sizable fractions of minimum daily requirements of a number of nutrients to popular foods, such as breakfast cereals, baked goods, pasta products, and low-calorie breakfast drinks. Nutrient additives include mainly vitamins, proteins, and minerals.

Vitamin D is an exceptional example of the value of the food additive concept. The major source of vitamin D for humans is a precursor compound called 7-dehydrocholesterol which is produced in the liver. It circulates to an area just under the skin and is converted to previtamin D_3 by the ultraviolet rays of sunlight. Previtamin D_3 then goes through a number of steps and is converted to vitamin D_3 and finally to active vitamin D. However, in many cases, exposure to the sun is sporadic and insufficient, especially in areas where there is normally insufficient sunshine or in cases where sunlight exposure is of insufficient duration. Thus, vitamin D is added to nearly all commercial milk in a ration of 10 micrograms of vitamin D (as cholecalciferol). This is equivalent to the old 400 IU per quart (0.95 liter). Vitamins A and C and some of the B vitamins are also added to some foods.

The addition of protein concentrate (produced from fish or soybeans) to components of the diet of inhabitants of underdeveloped countries has been used successfully to remedy the high incidence of protein malnutrition. It should be noted that soybean protein is incomplete and requires the addition of some amino acids in which it is

deficient. Children, especially, succumb in large numbers to the disease, kwashiorkor, that results from insufficient protein intake.

Among minerals, iron has received major attention as a food additive, mainly because of its role in preventing certain anemias.

FLAVORINGS

Flavorings are compounds, natural or synthetic, that are added to foods to produce flavors or to modify existing flavors. In the early days of human existence, salt, sugar, vinegar, herbs, spices, smoke, honey, and berries were added to foods to improve their taste or to produce a special, desirable taste. The variety of natural and synthetic flavorings available to the modern food technologist is very large. Essential oils provide a major source of flavorings. Essential oils are odorous components of plants and plant materials that give the characteristic odors of the materials from which they are extracted.

Because of the large production of orange juice, quantities of essential oil of orange are produced as byproducts. For this reason, there is little need for the production of synthetic orange flavoring.

Fruit extracts have been used as flavorings, but these are relatively weak when compared to essential oils and oleoresins. An oleoresin is a solvent extract of spices from which the solvent, usually a hydrocarbon, has been removed by distillation. Because of their weak effects, fruit extracts may be intensified by combining them with other flavorings.

Synthetic flavorings are usually less expensive and more plentiful than natural flavorings. On the other hand, natural flavorings are often more acceptable, but they are quite complex and difficult to reproduce synthetically. In fact, one of the problems with natural flavorings is that they may vary according to season and other uncontrollable factors. Synthetic flavorings, however, can be reproduced quite accurately. Many artificial flavors, such as amyl acetate (artificial banana flavor), benzaldehyde (artificial cherry flavor), and ethyl caproate (artificial pineapple flavor), are added to confectioneries, baked products, soft drinks, and ice cream. These flavorings are added in very small amounts, often 0.03% or less.

FLAVOR ENHANCERS

Flavorings either impart a particular flavor to food or modify flavors already present. Flavor enhancers, on the other hand, intensify flavors already present, especially when the desirable flavors are relatively weak. Monosodium glutamate (MSG) is one of the best known and most widely used flavor enhancers. This compound occurs naturally in many foods and in a certain seaweed that was used for centuries as a flavor enhancer in soups and other foods. It is only within the last hundred years that the reason for the effectiveness of the seaweed was discovered to be MSG. While it is effective at relatively low levels (parts per thousand), there are other compounds called flavor potentiators that also enhance flavors but are extremely powerful, effective in parts per million and even per billion. These compounds have been identified as nucleotides, and their effect is attributed to their synergistic properties (properties that intensify

the effect of natural flavor components). Two in this group are disodium inosinate and disodium GMP.

Several theories attempt to explain how MSG and other flavor enhancers and potentiators work. One theory is that they increase the sensitivity of the taste buds, thus increasing flavor. A second suggests that an increase in salivation as a result of the flavor enhancers will increase flavor perception. A third theory of intensified flavor perception is based on the observation that flavor enhancers produce certain physical sensations in the mouth such as coolness and heat.

ACIDULANTS

From the root word, *acid,* in acidulants, one can conclude that this class of compounds tends to lower the pH of any food into which the compounds are incorporated. Acidulants also enhance desirable flavors, and in many cases, such as in pickled products, are the major taste component. Vinegar (acetic acid, CH_3COOH) is added to relishes, chili sauce, ketchup, and condiments as a flavor component and to aid in the preservation of these products. Because the microbial spoilage of food is inhibited as the pH is lowered, acidulants are used for that purpose in many cases. Many acidulants occur naturally in foods (e.g., citric acid in citrus fruits, malic acid in apples, acetic acid in vinegars; all three are contained in figs). Tartaric acid is widely used to lend tartness and enhance flavor. Citric acid is widely used in carbonated soft drinks. Phosphoric acid is one of the very few inorganic acids used as an acidulant in foods. It is widely used, comprising 25% of all the acidulants in foods. Citric acid accounts for 60% of all acidulants used in foods.

In addition to their preservative and flavor enhancing effects, acidulants are used to improve gelling properties and texture. Acidulants are also used as cleaners of dairy equipment.

Acidulants may be used in the manufacture of processed cheese and cheese spreads for the purpose of emulsification as well as to provide a desirable tartness.

Acid salts may be added to soft drinks to provide a buffering action (buffers tend to prevent changes in pH) which will prevent excess tartness. In some cases, acid salts are used to inhibit mold growth (e.g., calcium propionate added to bread).

As has been pointed out, all microorganisms have a pH at which they grow best (see Chapter 3), and a range of pH above or below which they will not grow. Generally, it is not possible to preserve all foods by adding acid to the point where microorganisms will not grow. Most foods would be too acid to be palatable. The amount of acid may be enough to inhibit the growth of microorganisms provided that such treatment is combined with some other method of preservation. Certain dairy products, such as sour cream, and fermented vegetables, such as sauerkraut, are preserved with lactic acid produced by the growth of bacteria. Addition of the acid, along with holding at refrigerator temperatures above freezing, in combination will prevent growth of pathogenic and spoilage organisms. When sauerkraut is canned, it is given a heat process sufficient to destroy all spoilage and disease microorganisms.

Pickles are preserved by the addition of some salt, some acid, and a heat process sufficient to raise the temperature of all parts of the food to or near 212°F (100°C).

Pickled herring are preserved by the addition of some salt, some acetic acid (vinegar), and holding at refrigerator temperatures above freezing. In this case, the nonacid part of the acetic acid molecule has an inhibiting effect on the growth of microorganisms.

ALKALINE COMPOUNDS

Alkaline compounds are compounds that raise the pH. Alkaline compounds, such as sodium hydroxide or potassium hydroxide, may be used to neutralize excess acid that can develop in natural or cultured fermented foods. Thus, the acid in cream may be partially neutralized prior to churning in the manufacture of butter. If this were not done, the excess acid would result in the development of undesirable flavors. Sodium carbonate and sodium bicarbonate are used to refine rendered fats. Alkaline compounds are also added to chlorinated drinking water to adjust the pH to high enough levels to control the corrosive effects of chlorine on pipes and equipment. Sodium carbonate is also used in conjunction with other compounds to reduce the amount of hardness in drinking water. Sodium hydroxide is used to modify starches and in the production of caramel. Sodium bicarbonate is used as an ingredient of baking powder, which is used in baked products. (It is also a common household item used in a variety of cooking recipes.) Its action is described in the "Leavening Agents" section of this chapter. Alkaline compounds are used in the production of chocolate and to adjust the acidity level in grape juice and other fruit juices that are to be fermented in the production of wine.

It is important to note that some alkaline compounds, such as sodium bicarbonate, are relatively mild and safe to use, while others, such as sodium hydroxide and potassium hydroxide, are relatively powerful reagents and should not be handled by inexperienced people.

SWEETENERS

Sweetening agents are added to a large number of foods and beverages. Table sugar (sucrose), the most commonly used sweetener in the country, and corn syrup, are covered in Chapter 22 and therefore are not described in any detail here. Sweeteners include other sugars, as well as an abundance of natural and synthetic agents of varying strengths and caloric values.

Many sweeteners are classified as nonnutritive sweeteners. Although this classification might imply a lack of nutritional value, the implication is correct only in a relative sense. That is, the caloric value of a nonnutritive sweetener, such as aspartame, is about 4 cal/g, the same as that for sugar. However, because it takes only 1 g of aspartame to provide the same sweetness level as about 180 g of sugar (sucrose), it can be seen that the caloric contribution of aspartame is only about 0.5% that of sucrose. It is on this basis that a nonnutritive sweetener is classified as such.

The sweeteners described in this chapter are fructose, molasses, honey, maple sugar, lactose, maltose, some polyhydric alcohols (xylitol, sorbitol, mannitol), aspartame, saccharin, glycyrrhizin, and acesulfame K.

Fructose

Of the natural sugars other than sucrose used by humans, fructose (also known as levulose), a monosaccharide ($C_6H_{12}O_6$), is the sweetest (nearly twice as sweet as table sugar, sucrose) and it is the most water-soluble. It is hygroscopic, making it an excellent humectant when used in baked goods. The value of a humectant in baked goods is

that it retards dehydration. Solutions of fructose have a low viscosity that results in lower "body" feel than sucrose but have greater flexibility of use over a wide range of temperatures. Because of its greater solubility and more effective sweetness than sucrose, fructose is a better choice than sucrose when very sweet solutions are required, as fructose will not crystallize out of solution, whereas sucrose will. Fructose has sometimes been called fruit sugar, since it occurs in many fruits and berries. It also occurs as a major component in honey, corn syrup, cane sugar, and beet sugar. In fact, sucrose, a disaccharide, is composed of glucose and fructose. Of these two components, the glucose moiety, or portion, cannot be metabolized by people with diabetes, and it is for this reason that the ingestion of sucrose cannot be tolerated by them. Fructose, on the other hand, does not require insulin for its metabolism and can, therefore, be used by diabetic individuals. Its use also appears to reduce the incidence of dental caries. When used with saccharin, it tends to mask the bitter aftertaste of saccharin. As it apparently accelerates the metabolism of alcohol, it has been used to treat those suffering from overdoses of alcohol. It has been recommended as a rapid source of energy for athletes and, in combination with gluconate and saccharin, as an economic, effective, safe, low-calorie sweetener for beverages.

Molasses

Molasses can be considered a byproduct of sugar production (see Chapter 22). The use of molasses as a sweetener in human foods is largely in baked goods that include bread, cookies, and cakes. In addition to sweetening, molasses adds flavor and acts as a humectant. It is also used in baked beans and in the production of rum and molasses alcohol. (The greatest use of molasses, however, is in the production of animal feed). Molasses comprises about 60% sucrose, but the sucrose content can be lower, depending on the grade of the molasses and on the raw material from which it was produced. Thus, the sucrose content of cane blackstrap (the final fraction of cane molasses) is only about one-half that of beet blackstrap (the final fraction of beet molasses). The fractions produced before the blackstrap are of higher grades and are those usually used for human consumption. Blackstrap generally is used for industrial purposes.

Honey

Honey, a natural viscous syrup, comprises mainly invert sugar. It is produced from the nectar of flowers, which is mainly sucrose, by the action of an invertase enzyme that is secreted by the honey bee. Honey is used as a direct sweetener, as an additive in a number of products, including baked goods, as well as in other ways. It is relatively expensive.

Invert sugar, corn sugar, and corn syrup are covered in Chapter 22 and are not covered here.

Maple Sugar

Maple sugar is produced from the sap of the sugar maple tree. It is comprised mainly of sucrose and small amounts of other sugars, including invert sugar. Maple sugar is used in the manufacture of candies, fudge, baked goods, and toppings. It is among the most expensive of sweeteners.

Lactose

Lactose ($C_{12}H_{22}O_{11}$), the sugar component of mammalian milk, is less sweet and less water-soluble than sucrose. Although most babies and young children generally are able to metabolize this sugar, some are unable to do so. The ability to metabolize the sugar appears to decrease with age. When a person is unable to metabolize lactose, the ingestion of milk may cause intestinal discomfort, cramps, and diarrhea. The major source of lactose is whey, a cheese byproduct. Because lactose is not as sweet as sucrose, larger amounts can be used in those foods in which the texture benefits from a high solids content.

Maltose

Maltose ($C_{12}H_{22}O_{11}$), or malt sugar, is produced during the malting process in brewing (enzyme conversion of starch). It is converted to alcohol by the action of yeasts through an intermediate conversion to dextrose. This sugar is much less sweet than sucrose, and it is used mainly in the manufacture of baked goods and infant foods.

Xylitol

Xylitol is a polyhydric alcohol having the formula ($C_5H_7(OH)_5$). At present it is used as a sweetener in chewing gum, mainly because of its noncariogenic property (it has not been found to cause tooth decay). It occurs naturally as a constituent of many fruits and vegetables, and is a normal intermediary product of carbohydrate metabolism in humans and in animals. Commercially, it is produced by the hydrolysis of xylan (which is present in many plants) to xylose, which is then hydrogenated to produce xylitol. The xylitol is then purified and crystallized. Xylitol imparts a sweet taste, which also appears to have a cooling effect. As it is not metabolized by many microorganisms, it is quite stable.

Sorbitol

Sorbitol is a polyhydric alcohol ($C_6H_8(OH)_5$) that is found in red seaweed and in fruits (apples, cherries, peaches, pears, and prunes). It was first isolated from the sorb berries of the mountain ash, hence its name. It is used as an additive because of its humectant property as well as its sweetening effect. It is used in cough syrup, mouthwashes, and toothpastes. Another of its desirable properties is that it is not easily fermented by microorganisms. Because sorbitol is largely transformed to fructose by liver enzymes in the body, it is tolerated by diabetic individuals, as fructose is not dependent on the availability of insulin for its metabolism. Sorbitol can be produced industrially by the electrochemical reduction or catalytic hydrogenation of glucose.

Mannitol

Mannitol is a polyhydric alcohol having the formula ($C_6H_8(OH)_6$). It is used in chewing gum, pharmaceuticals, and in some foods. It is a naturally occurring sweetener in many plants, algae, and mold. It occurs in the sap of the manna tree, an ash native to southern Italy, and can also be made by the reduction of either of the monosaccharides

mannose or galactose. Industrially, it is produced by electrochemical reduction or catalytic hydrogenation methods. Although it is similar to sorbitol in many respects, it is less soluble than sorbitol.

Aspartame

Aspartame is the common name for aspartyl-phenylalanine. It is a combination of the two amino acids from which its name is derived. First produced in 1969, it is reputed to be about 180 times sweeter than sucrose. Like cyclamate, it was approved and later banned by the FDA. Exhaustive evidence of its safety has been presented by animal testing and by definition of its metabolic fate in animals and humans. It was subsequently reinstated as safe for use by the FDA.

Unlike saccharin and cyclamate, aspartame leaves no bitter aftertaste. It is quite expensive, about 200 times more so than sucrose, but as it is about 180 times sweeter than sucrose, its cost for obtaining a given unit of sweetness is not much more.

Saccharin

Saccharin, the imide of *o*-benzosulfonic acid, is used as a sodium or calcium salt. It is about 300 times sweeter than sucrose (table sugar). It may leave a bitter aftertaste, and its safety has been question as a result of some animal feeding tests. As an intense sweetener it is useful for diabetic individuals, and it reduces the incidence of dental caries.

STARCHES

Although starches differ from each other somewhat, depending on the plant from which they are extracted, they are sufficiently similar chemically to be often classified together as starch. The two basic starch polymers are amylose and amylopectin. Starch is used as a source of carbohydrate, and because it is relatively inexpensive, is often used as an extender. Its properties also make it useful as a thickening agent. The major source of starch is corn, but some starch is also produced from sorghum, potatoes, and wheat. More on starches is discussed in Chapters 2 and 18.

GUMS

Gums, a class of complex polysaccharides, are defined as materials that are dispersible in water and capable of making the water viscous. Many gums occur naturally in certain land and sea plants. Examples are gum arabic and agar. Many gums, such as the cellulose derivatives, are modified or semisynthetic, and some gums, such as the vinyl polymers, are synthetic. Gums are used to stabilize ice cream and desserts, thicken certain beverages and preserves, stabilize foam in beer, emulsify salad dressings, and form protective coatings for meat, fish, and other products. Gums add "body" and prevent settling of suspended particles in chocolate milk, ice cream, and desserts.

They may also prevent the formation of large ice crystals in frozen desserts. A significant potential for the use of gums lies in the production of certain low-calorie foods. For example, the oil in salad dressing can be replaced with gums to result in a product with the normal appearance, texture, and taste but without the calories normally associated with the product.

ENZYMES

Enzymes occur naturally in foods, and their presence may be either beneficial or detrimental, depending on the particular enzyme (see Chapter 8). When the presence of enzymes is undesirable, steps are taken to inactivate them. When their presence is desirable, either the enzymes or sources of the enzymes are intentionally added to foods. For example, the enzyme papain (from the papaya fruit) is added to steak to tenderize it. Many of the useful enzymes used in food processing are produced by microbes; consequently those microbes producing the desired enzyme may be added intentionally to food. For example, specific yeasts are intentionally added in the production of bread, beer, or cheese.

The use of enzymes as food additives presents no problem from the standpoint of safety, because enzymes occur naturally, are nontoxic, and are easily inactivated when desired reactions are completed. Enzymes called amylases are used together with acids to hydrolyze starch in the production of syrups, sugars, and other products.

Invertase

Certain enzymes, such as invertase, split disaccharides, such as sucrose (table sugar), to lower sugars (glucose and levulose). Invertase has many applications, and is used, for example, to prevent crystallization of the sucrose that is used in large amounts in the production of liqueurs. Without invertase, the liqueurs would appear cloudy.

Pectinase

Pectinases are enzymes that split pectin, a polysaccharide that occurs naturally in plant tissues, especially those of fruit. Pectin holds dispersed particles in suspension, as in tomato juice. Because it is desirable to keep the thick suspension in tomato juice, pectinases that occur naturally in it are inactivated by heat. On the other hand, products such as apple juice are customarily clear, and this is accomplished by adding commercial pectinase to the product, which degrades the pectin in the apple juice, resulting in the settling out of the suspended particles, which are then separated from the clear juice. In the manufacture of clear jellies from fruits, it is first necessary to add pectinase to destroy the naturally occurring pectin in order to clarify the juice. This pectinase must now be inactivated by heat. Then more pectin must be added to the clarified juice to produce the thick consistency of jelly. If the pectinase is not inactivated after clarification, the enzyme would also break down the newly added pectin required to produce the thick consistency.

Cellulases

Cellulases are enzymes that can break down cellulose, said to be the most abundant form of carbohydrate in nature. Cellulose, the principal structural material in plants,

is insoluble in water and is indigestible by humans and many animals. Ruminants are able to digest cellulose because of a cellulase (produced by microorganisms in the large stomach) contained in their gastric juice. Commercial applications of cellulases are not widespread at present. Cellulases are used for tenderizing fibrous vegetables and other indigestible plant material for the production of foods or animal feed.

Proteases

Proteases are enzymes that break down proteins, polypeptides, and peptides. Peptides are the structural units of which polypeptides consist, and polypeptides are larger structural units that make up the protein. There is a large number of specific proteases, and each attacks protein molecules at different sites, producing a variety of end products. Proteases are used to produce soy sauce from roasted soybeans, cheese from milk, and bread dough from flour. They are also used to tenderize meat and chill-proof beer which, if untreated, develops an undesirable haze when chilled.

Lipases

Lipases, the lipid (fat or oil) splitting enzymes, have limited commercial application, with oral lipases having the widest. Lipases prepared from oral glands of lambs and calves are used in a controlled way in the production of certain cheeses and other dairy products, as well as lipase-treated butter fat used in the manufacture of candles, confections, and baked products. Lipases are also used to remove fat residuals from egg whites and in drain cleaner preparations.

Glucose Oxidase

Glucose oxidase is an enzyme that specifically catalyzes the oxidation of glucose to gluconic acid. This reaction is important in preventing nonenzymatic browning, because glucose is a reactant in the undesirable browning reaction. The most important application of this enzyme is in the treatment of egg products, especially egg whites, prior to drying. Eggs treated with this enzyme before they are dried do not undergo nonenzymatic browning during storage, because the sugar has been removed. In some cases, the enzyme is added to remove traces of oxygen to prevent oxidative degradation of quality. Examples of this type of application are mayonnaise and bottled and canned beverages (especially beer and citrus drinks).

Catalase

Catalases are used to break down hydrogen peroxide (H_2O_2) to water and oxygen. Therefore, catalases are used when the presence of hydrogen peroxide is undesirable or when hydrogen peroxide is used for specific purposes, such as in bleaching, but then must be removed from the system. Examples of the latter case are the uses of hydrogen peroxide for preserving milk in areas where heat pasteurization and refrigeration are unavailable and in the manufacture of cheese from unpasteurized milk. Hydrogen peroxide is produced during the spray-drying process. Catalase is used to convert the unwanted H_2O_2 to water and oxygen.

SEQUESTRANTS

The role of sequestrants is to combine with metals, forming complexes with them and making them unavailable for other reactions.

$$M + S \rightarrow MS$$

where

M = metal
S = sequestrant
MS = complex.

Sequestrants, like many other additives used for enhancing specific properties of foods, occur naturally in foods. Many sequestrants have other properties; for example, citric, malic, and tartaric acids are acidulants but they also have sequestering properties.

Because metals catalyze oxidative reactions, sequestrants can be considered to have antioxidant properties. Thus, they stabilize foods against oxidative rancidity and oxidative discoloration. One of the important uses of sequestrants as additives is to protect vitamins, as these important nutrients are especially unstable when exposed to metal-catalyzed oxidation. Sequestrants are used to stabilize the color of many canned products and they help stabilize antioxidants. Sequestrants are especially helpful in stabilizing color and lipids in canned fish and shellfish. Because fish and shellfish naturally contain relatively high concentrations of metal, these products normally have poor color stability, and the lipids tend to rancidify during storage.

Sequestrants are also used to stabilize the flavors and odors in dairy products and the color in meat products.

POLYHYDRIC ALCOHOLS

In addition to their use as sweeteners, many polyhydric alcohols (also called polyols) are used to improve texture and moisture retention because of their affinity for water. Many polyols are present in foods naturally, glycerine (glycerol) being the predominant one. However, only four of the many polyols are allowed as food additives. They are glycerine, sorbitol, mannitol, and propylene glycol. All but the last have a moderately sweet taste (see section on sweeteners), although none are as sweet as sugar. Propylene glycol has a somewhat undesirable bitter taste, but is acceptable in small amounts. Sorbitol imparts a cool sensation. Glycerine, on the other hand, imparts a hot sensation.

Polyols are used in the production of dietetic products including beverages, candy, gum, and ice cream to contribute to texture as well as to sweetness. These compounds have a less adverse effect on teeth than sugar, because they are not fermented as quickly as sugar and are usually washed away before they can be utilized by microorganisms.

SURFACE-ACTIVE AGENTS

Surface-active agents affect the physical force at the interface of surfaces. Commonly called surfactants, they are present in all natural foods, because by their nature they

play a role in the growth process of plants and animals. They are defined as organic compounds that affect surface activities of certain materials. They act as wetting agents, lubricants, dispersing agents, detergents, emulsifiers, solubilizers, and so forth. One use for wetting agents is to reduce the surface tension of materials to permit absorption of water by the material. An example of their use is in powdered chocolate mixes used to prepare chocolate milk by addition of water.

Dispersions of materials depend on the reduction of interfacial energy, and this can be accomplished by certain surfactants.

Surfactants are used in the production of foods to prevent sticking, such as in untreated peanut butter. Surfactants are also used in cleaning detergents used on food equipment, and they can stabilize or break down foams.

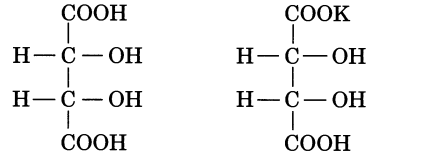
Emulsifiers, such as lecithin, mono- and diglycerides, and wetting agents, such as a class of chemicals known as "tweens," may be added to bakery products (to improve volume and texture of the finished products and the working properties of the dough and to prevent staling of the crumb), cake mixes, ice cream, and frozen desserts (to improve whipping properties). Except for the tweens, the chemicals cited above are natural components of certain foods.

LEAVENING AGENTS

Leavening agents are used to enhance the rising of dough in the manufacture of baked products. Inorganic salts, especially ammonium and phosphate salts, favor the growth of yeasts, which produce the carbon dioxide gas that causes dough to rise. Chemical reagents that react to form carbon dioxide are also used in baked goods. When sodium bicarbonate, ammonium carbonate, or ammonium bicarbonate is reacted with potassium acid tartrate, sodium aluminum tartrate, sodium aluminum phosphate, or tartaric acid, carbon dioxide is produced. Baking powder is a common household leavening agent that contains a mixture of chemical compounds that react to form carbon dioxide, producing the leavening effect. Baking powder can be either single acting or double acting, giving the desired leavening effect in different products. The chemistry is shown below.

Single-Acting Baking Powder (Quick-Acting Baking Powder):

The CO_2 is liberated when sodium bicarbonate (the base) reacts with potassium acid tartrate (the potassium salt of tartaric acid).



tartaric acid potassium acid tartrate

The reaction is as follows:

$$NaHCO_3 + KHC_4H_4O_6 \xrightarrow{H_2O} KNaC_4H_4O_6 + CO_2 + H_2O$$

sodium bicarbonate	potassium acid tartrate	sodium potassium tartrate	carbon dioxide	water

Double-Acting Baking Powder:

The double-acting type has two acid-reacting ingredients (monocalcium phosphate monohydrate and sodium aluminum sulfate). The hydrated form of monocalcium phosphate reacts with sodium bicarbonate to release a portion of CO_2 during mixing a batter or dough. The remaining sodium bicarbonate will react with sulfuric acid which is produced from the sodium aluminum sulfate in hot water.

First action:

$$3\,CaH_4(PO_4)_2 + 8\,NaHCO_3 \longrightarrow Ca_3(PO_4)_2 + 4\,Na_2HPO_4 + 8\,CO_2 + 8\,H_2O$$

monocalcium phosphate	sodium bicarbonate	tricalcium phosphate	disodium phosphate	carbon dioxide	water

Second action:

$$Na_2Al_2(SO_4)_4 + 6\,H_2O \xrightarrow{\text{heat}} 2\,Al(OH)_3 + Na_2(SO_4) + 3\,H_2SO_4$$

sodium aluminum sulfate	water	aluminum hydroxide	sodium sulfate	sulfuric acid

$$3\,H_2(SO_4) + 6\,NaHCO_3 \xrightarrow{H_2O} 3\,Na_2SO_4 + 6\,H_2CO_3$$

sulfuric acid	sodium bicarbonate	sodium sulfate	carbonic acid

In this reaction, the major portion of the CO_2 is released after the product is heated in the oven.

IONIZING RADIATION

Earlier in this chapter, the Food Additives Amendment of 1958 was discussed and it was shown that in the definition of a food additive, the statement: ". . . any source of radiation intended for such use . . ." is included. Thus, ionizing radiation is considered a food additive.

Irradiation does not leave a residue in food and it does not make it radioactive. The levels of irradiation allowed in food processing do not induce measurable radioactivity. Any radioactivity found in irradiated foods has been shown to be "background radiation" or that which is already present naturally. Irradiation does, however, cause small chemical changes in the food as do other methods of food processing.

Foods that have been irradiated must be labeled with the green international logo (see Fig. 13.1) to inform the consumer that the food has been processed by ionizing radiation. The words "Treated with Radiation" or "Treated by Irradiation" must also appear and must be in the same print style as the product name and be no smaller than one-third the size of the largest letter in the product name.

The effectiveness of this process is understood and agreed upon, but is it safe? The HACCP program discussed in Chapter 4 was developed to ensure the safety of the astronauts against food poisoning. They ate irradiated food. It has been established that ionization radiation of foods can destroy pathogenic bacteria but what about the

Figure 13.1. International Radiation Logo (green in color)

long-term effects of consumption of these products? The safety of irradiated foods has been tested in feeding studies for over 40 years. The studies include both animal and human subjects. Chemistry studies, feeding studies, and mutagenicity and teratogenicity studies have not revealed any confirmable negative evidence as to the wholesomeness of foods preserved by ionization radiation. Nutrient retention of irradiated foods is comparable to that of heat-processed foods. Irradiated foods may be more susceptible to oxidation but this can be controlled by use of low temperatures and elimination of oxygen.

The future of irradiation of foods is uncertain but it seems that scientific evidence and logic will have more effect on legislation in this area. There will always be risks, so food scientists must decide which will be the least likely cause of danger and proceed accordingly.

CHEMICAL PRESERVATIVES

The practice of preserving food by the addition of chemical is quite old, ordinary table salt (sodium chloride) having been used as a preservative for centuries. It might be surprising to think of a naturally occurring substance as a chemical preservative, but many chemical substances used in the preservation of foods occur naturally. When they are used with the proper intent, they can be used to preserve foods that cannot be easily preserved by other means. They should not be used as a substitute for sanitation and proper handling procedures. Sometimes chemicals are used together with other processes, such as holding at refrigerator temperatures above freezing.

To preserve food, it is necessary either to destroy all of the spoilage microorganisms that contaminate it or to create and maintain conditions that prevent the microbes from carrying out their ordinary life processes. Although preservation is aimed mainly at microbial spoilage, it must be remembered that there are other types of spoilage factors, such as oxidation.

Although foods can be sterilized (such as by heat processing) and contained in such a way as to prevent contamination by microbes during storage, it still is often necessary in some cases to forego sterilization, thus making it necessary to take other steps to prevent microbial degradation of the food. Foods can be protected against microbial attack for long periods (months to years) by holding them at temperatures below freezing (see chapter 12). They can be preserved for shorter periods (several days) by

holding them in ice or in a refrigerator at temperatures in the range 32 to 40°F (0 to 7.8°C) (see Chapter 12). Foods can also be preserved by altering them to make them incapable of supporting microbial growth. Drying is an example of this type of preservation. Foods must also be preserved against color and texture changes.

Quite often it is either impossible or undesirable to employ conventional preservation methods, and a large variety of food additives is available for use, alone or in combination with other additives or with mild forms of conventional processes, to preserve foods. Usually, chemical preservatives are used in concentrations of 0.1% or less. Sodium diacetate and sodium or calcium propionate are used in breads to prevent mold growth and the development of bacteria that may produce a slimy material known as rope. Sorbic acid and its salts may be used in bakery products, cheeses, syrups, and pie fillings to prevent mold growth. Sulfur dioxide is used to prevent browning in certain dried fruits and to prevent wild yeast growth in wines used to make vinegar. Benzoic acid and sodium benzoate may be used to inhibit mold and bacterial growth in some fruit juices, oleomargarines, pickles, and condiments. It should also be noted that benzoic acid is a natural component of cranberries.

Salt is an excellent microbe inhibitor, mainly as a result of its suppression of the water activity of the material to which it is added. Its effectiveness is enhanced when the food is also dried or smoked or both. Smoking also imparts a partial preservative effect.

Weak acids, such as sorbic acid, or salts of weak acids, benzoates, propionates, nitrites, certain chelating agents (chemicals that tie up metals and prevent the catalytic action of metals), and other chemical additives are effective preservatives. Natural spices also have antimicrobial properties. Antibiotics have been used as food additives and are still used to preserve animal feeds and human foods in some countries. Their use in human foods is banned in the United States and in some other countries.

Because many antimicrobial agents are generally toxic to humans, their use must be regulated not to exceed established levels beyond which they are hazardous to human health.

Nitrites, proven inhibitors of *Cl. botulinum,* and nitrates are added to cured meats, not only to prevent botulism, but also to conserve the desirable color as well as add to the flavor of the products. Some of these preservatives are discussed further in this chapter.

Sodium Chloride

When sufficient salt is added to food, it makes water unavailable to microorganisms. Because microorganisms require water to survive, they cannot exist when their water requirement is diminished by the addition of salt. We can reduce the amount of water available to microorganisms by lowering the water activity (a_w). (For more on a_w see Chapter 3.) Microorganisms require high levels of a_w. Most bacteria require a minimum a_w level of 0.96, although halophilic bacteria can grow at a_w of 0.75. Most yeasts grow at a_w levels of 0.90 and above, although a few can grow at an a_w level of 0.81. Molds can grow at lower a_w levels, with some able to grow at an a_w level of 0.62. While salt preserves foods mainly by lowering the a_w, the chloride ion is believed to inhibit bacterial growth, independently.

Some precautions must be observed in the salting preservation of flesh-type foods, such as fish or meats. When these products are salted, several days will be required before enough salt has diffused into all parts of the product to inhibit the growth of microorganisms. If, therefore, precautions are not observed, the growth of spoilage or

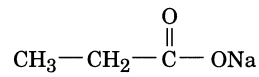
even disease-causing bacteria may occur in some parts of the food before enough salt has diffused into the product to inhibit growth. The usual procedure is to hold products under refrigeration during salting until there has been an adequate "take-up" of salt throughout the food. Fish and meats should never be held at temperatures above 60°F (15.6°C) during salting. Preferably, holding temperatures during such procedures should be at 40°F (4.4°C) or slightly below.

Salted, undried meats, such as corned beef, should be held at 40°F (4.4°C) or below at all times after curing because there are some microorganisms that may still grow at salt concentrations present in such products. Chipped beef, which is dried as well as salted, has a low enough moisture content to prevent the growth of all microorganisms and may be held at room temperature.

Salt cod, which has a moisture content of 40% or higher, should be held at temperatures of 40°F (4.4°C) or slightly below because it is subject to spoilage through bacterial growth. On the other hand, well-dried salt cod and certain types of salted and smoked herring that have dried during smoking may be held at room temperature without spoilage.

Fatty Acids

The salts of certain fatty acids have an inhibitory effect on the growth of microorganisms. Thus, sodium diacetate (a mixture of sodium acetate and acetic acid) and sodium or calcium propionate



sodium propionate

are added to bread and other bakery products to prevent mold growth, as well as the development of a slimy condition known as "ropiness," which results from the growth of certain aerobic, spore-forming bacteria (see Chapter 3 for the definition of spore-forming bacteria). Caprylic acid, CH_3CH_2—CH_2—CH_2—COOH, or its salts or the salts of other fatty acids may be used in cheese to prevent the growth of mold.

As pointed out previously, it is the nonacid part of the molecule of fatty acids or their salts that inhibits the growth of microorganisms. It is believed that the effect of these compounds is the destruction of the cell membrane of microorganisms.

Sulfur Dioxide

Sulfur dioxide (SO_2) is used in some foods to inhibit the growth of microorganisms. Sulfur dioxide may be used as such, or a source of this compound such as sodium bisulfite ($NaHSO_3$) may be added to the foods. Sulfur dioxide inhibits a rather narrow range of microorganisms and is usually applied together with another chemical inhibitor to prevent the growth of undesirable yeasts or bacteria in fruit juices, which are stored prior to fermentation, in the production of wine or vinegar. Sulfur dioxide may inhibit microbial growth by preventing the utilization of certain carbohydrates as a source of energy or by tying up certain compounds concerned with the metabolism of some microorganisms.

For many years, sulfiting agents have been classified as GRAS (generally regarded as safe) substances by the FDA for use as food preservatives when used in accordance

with GMP (good manufacturing practice). But in 1986, following several deaths from the consumption of fresh fruits or vegetables that had been treated with sulfites, the FDA withdrew the GRAS status of sulfites for this use. It was found that asthmatic individuals react, sometimes severely, when exposed to sulfites. Also, because sulfites have been found to destroy thiamin, these agents may not be used in meats and other foods containing thiamin. Although sulfites may still be used in foods that have not been excluded by the FDA, their presence must be declared on the label when their concentrations exceed 10 ppm (parts per million). Research has shown that in concentrations of 10 ppm or less, these agents should not cause adverse reactions in humans.

Sorbic Acid

Sorbic acid, $CH_3—CH=CH—CH=CH—COOH$, inhibits the growth of both yeasts and molds. This compound is most effective at pH 5.0 or below. This compound can be metabolized by humans, as can fatty acids, and hence is generally recognized as safe. Sorbic acid is used in certain bakery products (not yeast-leavened products, because it inhibits yeast growth), in cheeses, and in some fruit drinks, especially for the purpose of preventing molding. It is believed to inhibit the metabolic enzymes required by certain microorganisms for growth and multiplication.

Sodium Nitrite

Sodium nitrite ($NaNO_2$) is added to some food products to inhibit bacterial growth (especially *Cl. botulinum*) and to enhance color. It is added to most cured meats, including hams, bacon, cooked sausage (such as frankfurters, bologna, salami), and to some kinds of corned beef. Nitrite provides for the red or pink color of the cured and cooked sausages and of the other cured products after cooking. The nitrite combines with the reddish pigment of meat, the myoglobin, and prevents its oxidation. If the meat were not treated with nitrite, it would discolor to a brown color during cooking or during storage. When red meat is heated, as in cooking, the color turns from red to gray or brown as a result of the conversion of myoglobin to the oxidized form, metmyoglobin. On extremely long or extremely high heating or on exposure to light and oxygen, even the nitrited myoglobin may be oxidized to metmyoglobin, with the result that the red or pink color is lost.

In addition to stabilizing the color of cured or cured and cooked meats, the industry claims that nitrite acts as a preservative in that it tends to prevent the growth of spores of *Cl. botulinum* that may be present. *Cl. botulinum*, of course, is the most dangerous disease-causing organism.

Nitrite is also used in some fish products, such as smoked whitefish and chubs, for the specific purpose of preventing the growth of *Cl. botulinum*.

Sodium or potassium nitrite may not be used in meats or on fish that are to be sold as fresh. In cured products, it is allowed in concentrations not to exceed 0.0156% (156 parts of nitrite per million parts of the food). The amounts to ¼ oz or 7.09 g per 100 lbs of meat. In practice, however, it is closer to 120 ppm or less. The residual nitrite or that which actually appears in the final product is much less. A study done by Robert Cassens of the University of Wisconsin in 1995 showed residual levels of nitrite as low as 7 ppm for bacon, 6 ppm for sliced ham, and 4 ppm for hot dogs (expressed

as nitrite ion). Numerous factors affect residual nitrite levels but it is accurate to say that the amounts are much lower than that added at the time of processing. There is some question as to whether or not nitrites should be allowed in food in any concentration. It has been found that nitrite-cured products, especially those cooked at high temperatures, such as bacon, may develop nitrosamines, compounds formed by the reaction of nitrites with amines, and nitrosamines are known to be extremely carcinogenic or cancer-promoting. It is clear that the amount of nitrites used must be minimized but the level must remain high enough to protect against botulism and other microbiologically based foodborne diseases.

Cured meats are not the only sources of nitrites in the diet. Vegetables, baked goods, cereals, and water are also sources. Nitrites can also be made in the body from intakes of nitrates (NO_3) by a simple reduction. This can happen in the oral cavity as a result of action of bacteria in the saliva. Vegetables account for about 85% of our dietary intake of nitrates.

Processing methods and formulations have changed dramatically. The result is lowered residual nitrites and decreased levels of volatile nitrosamines. Some estimates are that the levels are one-third of those of a decade ago. This must be placed in proper perspective, however, because it is minor in relation to nitrite synthesized by the body. Steps can be taken to reduce amounts of nitrites ingested but, to ensure microbiological safety, their continued use in cured meats seems inevitable.

Oxidizing Agents

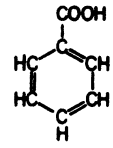
Oxidizing agents, such as chlorine, iodine, and hydrogen peroxide, are not ordinarily used in food, but they are used to sanitize food-processing equipment and apparatus and even the walls and floors of areas where food is processed. Thus, there is no doubt that small residuals, especially of chlorine or iodine, can get into food.

Hydrogen peroxide may be used to destroy the natural bacterial flora of milk, prior to inoculation with cultures of known bacterial species, for producing specific dairy products. In such cases, all of the residual hydrogen peroxide must be removed by treatment with the enzyme catalase (see Chapter 8). This treatment with catalase must be carried out prior to the inoculation of milk with cultures of desirable bacteria; otherwise the hydrogen peroxide will destroy the added bacterial culture, the growth of which is the objective of culturing milk.

Oxidizing agents are believed to inhibit and destroy the growth of microorganisms by destroying certain parts of the enzymes essential to the metabolic processes of these organisms.

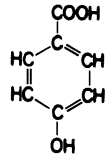
Benzoates

The benzoates and parabenzoates have been used as preservatives mainly in fruit juices, syrups (especially chocolate syrup), candied fruit peel, pie fillings, pickled vegetables, relishes, horseradish, and some cheeses. The probable reason that the benzoates and the related parabenzoates have been allowed as additives to food is that benzoic acid is present in cranberries as a natural component in concentrations that are higher than 0.1%. Benzoic acid or its sodium salt is allowed in food in concentrations up to



benzoic acid

0.1%. Parahydroxybenzoic acid or its esters, for instance, propyl para-hydroxybenzoic acid, may also be used.



para-hydroxybenzoic acid

The benzoates are most effective in acid foods in which the pH is as low as 4.0 or below. The parabenzoates are said to be more effective than the benzoates over a wider range of pH and against wider groups of microorganisms.

Investigations have indicated that benzoates prevent the utilization of energy-rich compounds by microorganisms. It has also been found that when bacteria form spores in the presence of benzoate, the spore may take up water and germinate to the point of bursting and shedding the spore wall, but enlargement and outgrowth into the vegetable cell with subsequent cell division and multiplication does not occur.

COLORANTS

We are accustomed to specific colors in certain food, and colors often provide a clue to the quality of the foods. Color additives can be categorized into three major types: natural, nature-identical, or synthetic.

Many colorants (compounds that add colors to foods) are natural, and these include the yellow from the annatto seed; green from chlorophyll; orange from carotene; brown from burnt sugar; and red from beets, tomatoes, and the cochineal insect. Natural colors are simply pigments obtained from animal, vegetable, or mineral sources.

If synthetic counterparts of colors and pigments are derived from natural sources, the term "nature-identical" applies. These include the pure carotenoids such as canthaxanthin (red), apocarotenal (orange-red), and beta-carotene (yellow-orange). These have all gone through toxicological studies and are approved by the FDA. Canthaxanthin and apocarotenal have maximum addition limits but beta-carotene can be added at the necessary level to accomplish its intended purpose.

Some colorants, however, are derived from synthetic dyes. The synthetic dyes in use have been approved and certified by the FDA. These certified color additives are divided into two groups: FD&C dyes and FD&C lakes. Dyes are water-soluble and are available in powders, granules, liquids, blends, and pastes. GMPs suggest that they not be used in amounts exceeding 300 ppm. The lakes are water-soluble FD&C certified dyes on a substratum of aluminum hydrate or aluminum hydroxide. The lakes must also be certified by the FDA. They are useful in foods that have very little water such as coloring oils. They are used in icings, fondant coatings, cake and doughnut mixes, hard candy, and gum products. They do not solubilize as do dyes but color by dispersion rather than solution.

In 1960 the Color Additive Amendments separated "color additives" from "food additives." Colors (which include black, white, and intermediate grays) no longer were to be classified as food additives. In determining whether a color additive is safe, the FDA must take into account the probable consumption of the additive and of any substance formed as a result of its use. There is also a cancer clause similar to the Delaney Clause in the amendments.

Some compounds are not color additives but are used to produce a white color. Thus, oxidizing agents including benzoyl peroxide, chlorine dioxide, nitrosyl chloride, and chlorine are used at the end of the production cycle to whiten wheat flour, which is pale yellow in color if untreated. Titanium dioxide, on the other hand, is considered a color additive and may be added to some foods, such as artificial cream or coffee whiteners to add a white color.

Part III

Handling and Processing of Foods

18

Dielectric, ohmic and infrared heating

Dielectric (microwave and radio frequency) energy and infrared (or radiant) energy are two forms of electromagnetic energy (Fig. 18.1). They are both transmitted as waves, which penetrate food and are then absorbed and converted to heat. In contrast, ohmic (or resistance) heating uses the electrical resistance of foods to directly convert electricity to heat.

Foods can be heated by either direct or indirect methods: dielectric and ohmic heating are direct methods in which heat is generated within the product, whereas infrared heating is an indirect method that relies on heat that is generated externally being applied to the surface of the food mostly by radiation, but also by convection and to a lesser extent, conduction.

The main differences between dielectric, ohmic and infrared energy can be summarised as follows:

- Dielectric energy induces molecular friction in water molecules to produce heat, whereas ohmic heating is due to the electrical resistance of a food and infrared energy is simply absorbed and converted to heat.
- Dielectric heating is determined in part by the moisture content of the food, whereas the extent of heating by radiant energy depends on the surface characteristics and colour of the food and ohmic heating depends on the electrical resistance of the food.
- Dielectric and ohmic heating are used to preserve foods, whereas infrared radiation is mostly used to alter the eating qualities by changing the surface colour, flavour and aroma.
- Commercially, microwaves and radio frequency energy are produced at specified frequency bands that are allocated to prevent interference with radio transmissions, whereas radiant heat is less controlled and has a wider range of frequencies. Ohmic heating uses mains frequency electricity.
- The depth of penetration into a food is directly related to frequency; the lower frequency dielectric energy penetrates more deeply than radiant energy. In contrast, ohmic heating penetrates throughout the food instantly.
- The thermal conductivity of the food (Chapter 1) is a limiting factor in infrared heating, whereas it is not so important in dielectric and ohmic heating.

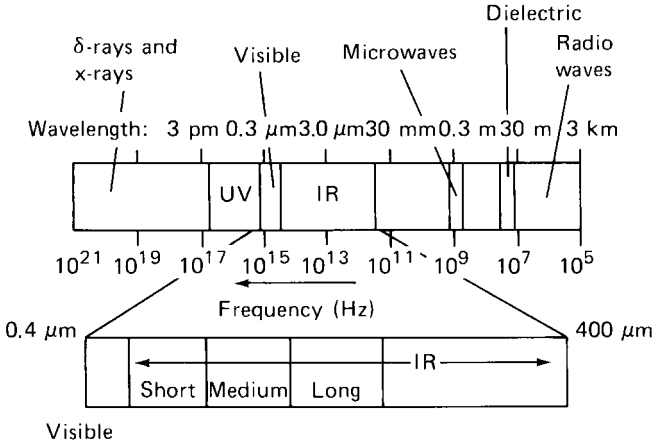


Fig. 18.1 Electromagnetic spectrum.
(Courtesy of the Electricity Council.)

18.1 Dielectric heating

18.1.1 Theory

The majority of foods contain a substantial proportion of water. The molecular structure of water consists of a negatively charged oxygen atom, separated from positively charged hydrogen atoms and this forms an electric dipole. When a microwave or radio frequency electric field is applied to a food, dipoles in the water and in some ionic components such as salt, attempt to orient themselves to the field (in a similar way to a compass in a magnetic field). Since the rapidly oscillating electric field changes from positive to negative and back again several million times per second, the dipoles attempt to follow and these rapid reversals create frictional heat. The increase in temperature of water molecules heats surrounding components of the food by conduction and/or convection. Because of their widespread domestic use, some popular notions have arisen that microwaves 'heat from the inside out'. What in fact occurs is that outer parts receive the same energy as inner parts, but the surface loses its heat faster to the surroundings by evaporative cooling. It is the distribution of water and salt within a food that has the major effect on the amount of heating (although differences also occur in the rate of heating as a result of the shape of the food, at its edges etc.).

The depth of penetration of both microwaves and radio frequency energy is determined by the dielectric constant and the loss factor of the food. These properties have been recorded for some foods (Kent, 1987), (Table 18.1). They vary with the moisture content and temperature of the food and the frequency of the electric field. In general, the lower the loss factor (i.e. greater transparency to microwaves) and the lower the frequency, the greater the penetration depth. It is possible to choose a frequency from the permitted bands that will give a suitable electric field strength for a given loss factor. Because most foods have a high moisture content and therefore a high loss factor, they readily absorb microwave and radio frequency energy and flash-over is not a problem. However, care is needed when selecting equipment for drying low moisture foods (Section 18.1.3) to prevent the electric field strength from exceeding a level at which flash-over would take place. Radio frequency energy is mostly used to heat or evaporate

Table 18.1 Dielectric properties of materials at 20–25°C and 2450 MHz

Material	Dielectric constant ($F\,m^{-1}$)	Loss factor	Penetration depth (cm)
Banana (raw)	62	17	0.93
Beef (raw)	51	16	0.87
Bread	4	0.005	1170
Brine (5%)	67	71	0.25
Butter	3	0.1	30.5
Carrot (cooked)	71	18	0.93
Cooking oil	2.6	0.2	19.5
Distilled water	77	9.2	1.7
Fish (cooked)	46.5	12	1.1
Glass	6	0.1	40
Ham	85	67	0.3
Ice	3.2	0.003	1162
Paper	4	0.1	50
Polyester tray	4	0.02	195
Potato (raw)	62	16.7	0.93

Adapted from Mudget (1982), Buffler (1993) and Mohsenin (1984).

moisture from a product, whereas higher frequency microwaves are used for defrosting and low pressure drying (Jones, 1987). Garcia and Bueno (1998) describe improved energy efficiency from combined microwave and hot air drying.

Microwaves

The depth of penetration of microwaves is found from the loss factor and the frequency of the microwaves:

$$x = \frac{\lambda_0}{2\pi\sqrt{(\epsilon' \tan \delta)}} \qquad 18.1$$

where x (m) = the depth of penetration; λ (m) = the wavelength, ϵ' = dielectric constant and tan $\delta(\epsilon''/\epsilon')$ = loss tangent (or loss factor or dissipation constant).

The power absorbed by the food is found using:

$$P = 55.61 + 10^{-14} f E^2 \epsilon'' \qquad 18.2$$

where P ($W\,m^{-3}$) = power per unit volume, f (Hz) = frequency and E ($V\,m^{-1}$) = electrical field strength.

Microwave penetration increases dramatically when water changes phase to ice (Fig. 18.2), possibly because the molecules are less free to move or absorb energy from the

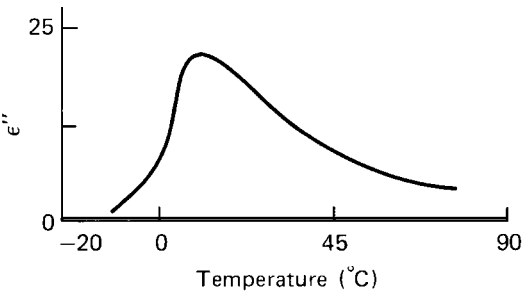


Fig. 18.2 Variation in dielectric loss factor of water and ice. (After Lewis (1990).)

alternating electric field. Ice therefore has a lower loss factor than water and this has important implications for microwave thawing and tempering applications (Section 18.1.3). Glass, papers and some polymer films have a low loss factor and are not therefore heated. Metals reflect microwaves and are not heated (Chapter 24), therefore making microwave ovens very efficient in energy use as the metal oven is not heated.

Radio frequency heating

This operates using a similar principle to microwave heating, but at lower frequencies (Fig. 18.1). Food is passed between electrodes and a radio frequency voltage is applied across the electrodes. This changes the orientation of water dipoles in a similar way to microwaves and results in very rapid heating. Radio frequency heating allows greater concentration of heat energy, selectivity in the location of heating and accuracy in control of the duration of heating. However, the thickness of the food is restricted by the distance between the capacitor plates, which is an important limitation of the method.

A simple method to calculate the amount of radio frequency energy needed for a particular process is

$$E = \frac{m(\theta_1 - \theta_2)C_p}{863} \qquad 18.3$$

where E = energy supplied (kW), m = mass flow rate of product (kg h^{-1}), θ_1 = final product temperature (ºC), θ_2 = initial product temperature (ºC), C_p = specific heat (kJ^{-1} $kg^{-1}K^{-1}$) (courtesy of Strayfield International).

There are a number of additions to the calculated amount of energy required:

- 1 kW is added for each 1.4 kg of water to be evaporated per hour in a drying application.
- An additional 10–20% of energy required is added to account for surface cooling, depending on the surface area to volume ratio of the product.
- If it is assumed that the equipment is 65% efficient in the use of energy supplied, an additional correction is needed to calculate the actual power requirement.

In drying applications for baked goods, radio frequency ovens heat the product to a point at which rapid evaporation of water can take place and then supply the latent heat of evaporation (Chapter 15). If the product is to be dried to around 4% moisture, this is usually 'free' moisture which is easily removed at 100ºC. However, for lower final moisture contents, it is necessary to remove moisture that is 'bound' into the cellular structure of the food, and higher temperatures are needed (see Section 1.5). Typically a temperature of 102–105ºC is needed to achieve 3% moisture, 105–110ºC for 2% moisture and 116ºC for 1.5% moisture. When products are reduced to these very low moisture levels, there are likely to be changes to the colour of baked goods that are similar to those found in conventional ovens. The advantages of microwave and radio frequency heating can be summarised as:

- heating is rapid
- the surface of the food does not overheat, which produces minimum heat damage and no surface browning
- equipment is small, compact, clean in operation and suited to automatic control
- there is no contamination of foods by products of combustion.

18.1.2 Equipment

Microwave equipment consists of a microwave generator (termed a *magnetron*) (Fig. 18.3), aluminium tubes named *wave guides*, and a metal chamber for batch operation, or a tunnel fitted with a conveyor belt for continuous operation. Because microwaves heat all biological tissues, there is a risk of leaking radiation causing injury to operators, particularly to eyes which have insufficient blood flow to provide sufficient cooling. Chambers and tunnels are therefore sealed to prevent the escape of microwaves. Detailed descriptions of component parts and operation of microwave heaters are given by Copson (1975) and Buffler (1993).

The magnetron is a cylindrical diode ('di' meaning two and 'electrode'), which consists of a sealed copper tube with a vacuum inside. The tube contains copper plates pointing towards the centre like spokes on a wheel. This assembly is termed the 'anode' and has a spiral wire filament (the cathode) at the centre (Fig. 18.3). When a high voltage (e.g. 4000 V) is applied, the cathode produces free electrons, which give up their energy to produce rapidly oscillating microwaves, which are then directed to the waveguide by electromagnets. The waveguide reflects the electric field internally and thus transfers it to the heating chamber. It is important that the electric field is evenly distributed inside the heating chamber to enable uniform heating of the food. In batch equipment a rotating antenna or fan is used to distribute the energy, or the food may be rotated on a turntable. Both methods reduce shadowing (areas of food which are not exposed to the microwaves). In continuous tunnels a different design of antennae is used to direct a beam of energy over the food as it passes on a conveyor. It is important that the power output from the magnetron is matched to the size of the heating chamber to prevent flash-over. Power outputs of continuous industrial equipment range from 30 to 120 kW.

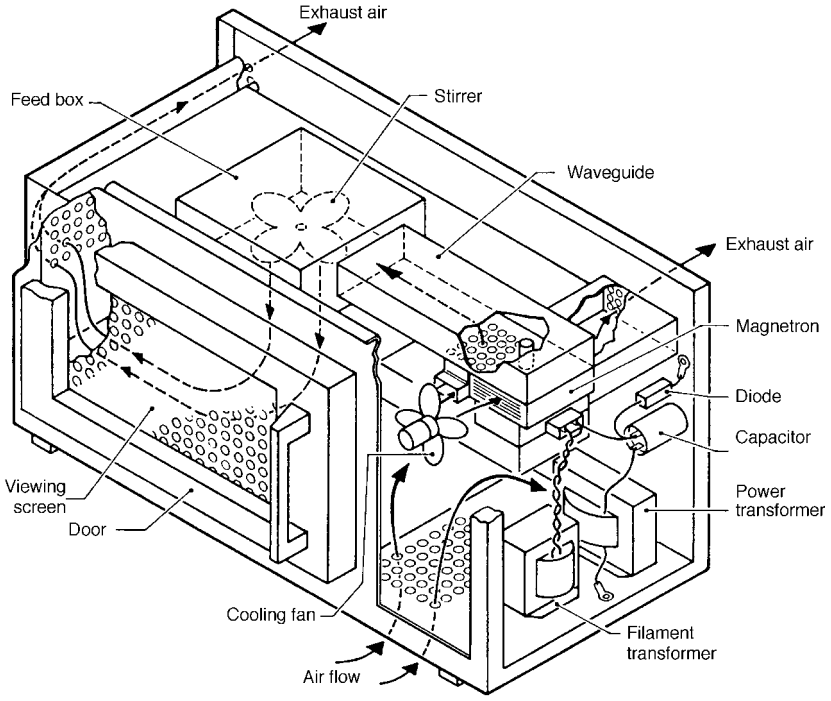


Figure 18.3 A microwave oven showing the magnetron.
(From Buffler (1993).)

Radio frequency heaters consist of banks of capacitor plates, most often located at the end of bakery tunnel ovens (Chapter 16) or conveyor driers (Chapter 15) with the conveyor band passing between the plates. The electrical circuit is arranged so that the food becomes an essential electrical component. Variations in the amount of food passing between the plates, its temperature and moisture content, will therefore cause a variation in the power output of the generator. This is a valuable self controlling feature: for example, the loss factor of a food falls as the moisture content is reduced and the power output correspondingly falls, so reducing the possibility of burning the food.

18.1.3 Applications

The high rates of heating and absence of surface changes to the food have led to studies of dielectric heating of a large number of foods. The most important industrial applications are thawing, tempering, dehydration and baking. These are reviewed by Rosenberg and Bogl (1987a) and Decareau (1985, 1990). Other applications, which involve bulk heating of foods with higher moisture contents (for example blanching and pasteurisation), are less successful. This is due to the low depth of penetration in large pieces of food and to evaporative cooling at the surface, which results in survival of large numbers of micro-organisms. These applications are discussed briefly in this section and are reviewed by Rosenberg and Bogl (1987b). Accelerated freeze drying by microwaves has been extensively investigated (Copson, 1975), but the process remains expensive and is not widely used commercially (Chapter 22).

Thawing and tempering

During conventional thawing of frozen foods (Chapter 21), the lower thermal conductivity of water, compared with ice, reduces the rate of heat transfer and thawing slows as the outer layer of water increases in thickness. Microwaves and radio frequency energy are used to rapidly thaw small portions of food and for melting fats (for example butter, chocolate and fondant cream) (Jones, 1987). However, difficulties arise with larger (e.g. 25 kg) frozen blocks (for example egg, meat, fish and fruit juice) used in industrial processes. Water has a higher loss factor than ice and, as a result, heats rapidly once the ice melts. In the large blocks, thawing does not take place uniformly, and some portions of the food may cook while others remain frozen. This is overcome to some extent by reducing the power and extending the thawing period or by using pulsed microwaves to allow time for temperature equilibration.

A more common application is '*tempering*' frozen foods. Here the temperature is raised from around −20ºC to −3ºC and the food remains firm but is no longer hard. After frozen food has been tempered, it is more easily sliced, diced or separated into pieces. Tempering is widely used for meat and fish products, which are more easily boned or ground at a temperature just below the freezing point, and for butter and other edible fats. If foods are tempered but not allowed to melt, the lower energy cost gives a good return on investment in dielectric equipment. The energy required to temper frozen beef, for example, is 62.8 J/g from −17.7 to −4.4ºC whereas 123.3 J/g is needed to raise the temperature a further 2.2ºC as more rapid melting begins to occur (Decareau, 1990). Production rates range from 14 t of meat per hour or 1.5–6 t of butter per hour in equipment which has power outputs of 25–150 kW. The advantages over conventional tempering in cold rooms include:

- faster processing (for example meat blocks are defrosted in 10 min instead of several days in a cold room)

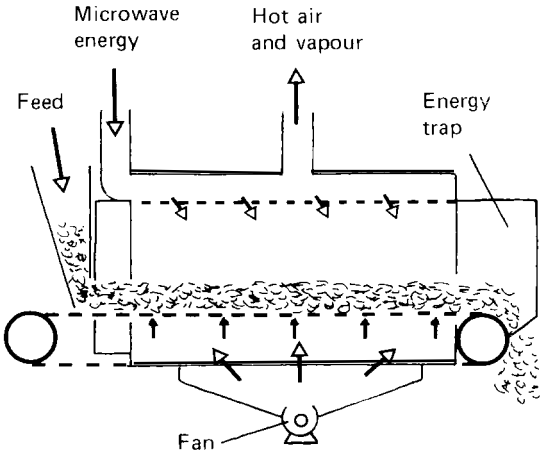


Fig. 18.4 Continuous microwave finish drying equipment. (After Decareau (1985).)

- there is a minimal amount of food being processed at any one time and little loss or spoilage in the event of a process delay
- greater flexibility in operation
- the cost of operating a refrigerated tempering room is eliminated
- no drip loss or contamination, which improves product yields and reduces nutritional losses
- improved plant productivity and simplified production scheduling
- savings in storage space and labour
- more hygienic defrosting because products are defrosted in the storage boxes
- better control over defrosting conditions and hence improved product quality.

Dehydration

The main disadvantages of hot-air drying are:

- low rates of heat transfer, caused by the low thermal conductivity of dry foods (Chapter 1, Table 1.5)
- damage to sensory characteristics and nutritional properties caused by long drying times and overheating at the surface
- oxidation of pigments and vitamins by hot air
- case hardening (Chapter 15).

Microwaves and radio frequency energy overcome the barrier to heat transfer caused by the low thermal conductivity. This prevents damage to the surface, improves moisture transfer during the later stages of drying and eliminates case hardening. The radiation selectively heats moist areas while leaving dry areas unaffected. It is not necessary to heat large volumes of air, and oxidation by atmospheric oxygen is minimised. However, the higher cost of microwaves and radio frequency units, together with the smaller scale of operation, compared with traditional methods of dehydration, restrict microwave drying to 'finishing' (removing the final moisture) of partly dried or low-moisture foods (Fig. 18.4).

For example, in pasta drying the fresh pasta is pre-dried in hot air to 18% moisture and then in a combined hot air and microwave drier to lower the moisture content to 13%. Drying times are reduced from 8 h to 90 min, bacterial counts are 15 times lower, there is

a reduction in energy consumption of 20–25%, the drying tunnel is reduced from 36–48 m to 8 m, clean-up time is reduced from 24 to 6 person-hours and there is no case hardening (Decareau, 1985, 1990). In grain finish drying, microwaves are cheaper, more energy efficient and quieter than conventional methods and do not cause dust pollution. The lower drying temperature also improves grain germination rates.

In conventional freeze drying, the low rate of heat transfer to the sublimation front limits the rate of drying (Chapter 22). Microwave freeze drying overcomes this problem because heat is supplied directly to the ice front. However, careful control over drying conditions is necessary to prevent localised melting of the ice. Any water produced in the drying food heats rapidly, owing to the higher loss factor, and causes a chain reaction, leading to widespread melting and an end to sublimation.

Baking

The efficiency of baking is improved by radio frequency or microwave finishing, for thin products such as breakfast cereals, babyfoods, biscuits, crackers, crispbread and sponge cake. Conventional ovens operate effectively when products have relatively high moisture contents, but the thermal conductivity falls as baking proceeds, and considerable time is necessary to bake the centre of the product adequately without excessive changes to the surface colour. Radio frequency or microwave heaters are located at the exit to tunnel ovens (Chapter 16) to reduce the moisture content and to complete the baking without further changes in colour. This reduces baking times by up to 30% and hence increases the throughput of the ovens. Meat pies, which require a good crust colour in addition to pasteurisation of the filling, can be baked in about one third of the time required in a conventional oven by the use of radio frequency heating (Jones, 1987). Other advantages include:

- increases in production by up to 50%
- savings in energy, space and labour costs
- close control of final moisture contents (typically $\pm$ 2%) and automatic levelling of moisture contents as only moist areas are heated
- separate control over baking and drying stages allows separate contro1 over internal and external product colour and moisture content
- improved product texture and elimination of ‘centre bone’ (dense dough in the centre of cookies)
- improved taste as flavours are subjected to shorter periods at high temperatures.

Other applications

Compared with conventional cooking, microwave *rendering* of fats improves the colour, reduces fines by 95% and costs by 30% and does not cause unpleasant odours (Decareau, 1985). Microwave *frying* is not successful when deep baths of oil are used, but can be used with shallow trays in which the food is heated rapidly (Chapter 17). There is also less deterioration in oil quality (Copson, 1975). Doughnuts are cooked without oil using microwaves, which reduces processing times by 20% and increases product yield by 25% (Schiffman *et al.*, 1972). Other commercial microwave cooking applications include bacon and meat patties for the fast-food industry and investigation of skinless frankfurters and other sausage products by setting meat emulsions in microwave transparent moulds (Decareau, 1990).

Blanching by microwaves has been extensively investigated, but at present the higher costs, compared with steam blanching (Chapter 10), have prevented its use for relatively

low-value vegetables. Microwave blanching of products that are more difficult to blanch by conventional methods is under development but may be limited by the high capital investment. Studies of combined steam and microwave blanching are reported to reduce blanching time (Huxsoll *et al.*, 1970).

Pasteurisation of packed complete pasta meals, soft bakery goods and peeled potatoes by microwaves is reported by Brody (1992). Most systems developed so far involve packaging the products in flat packages using thermoform/vacuum/gas flush seal equipment (Chapters 20 and 25). Packages are heated in tunnel conveyors, up to 25 m long, using a combination of microwaves and hot air at 70–90ºC, followed by an equilibration stage where the slowest heating parts of the packs reach 80–85ºC within 10 min. The packs are then cooled to 1–2ºC and have a shelf life of approximately 40 days at 8ºC. Details of a procedure for the microwave pasteurisation of fruit juices, to inactivate pectinesterase, are reported by Copson (1975) and for fruits in syrup by Brody (1992).

Sterilisation by microwaves is achieved in laminated pouches made from polypropylene/EVOH or PVDC/polypropylene (Chapter 24) in the Multitherm process. The pouches, which are transparent to microwaves, are formed and filled from a continuous reel of film but are not separated. This produces a chain of pouches that passes through a continuous hydrostat system, similar to a small hydrostatic steam steriliser (Chapter 12). In this case the pouches are submerged in a medium that has a higher dielectric constant than the product and heating is by microwaves instead of steam. In a system described by Stenstrom (1972, 1973), the product passes through seven liquid baths, heated at up to 90ºC, and the final sterilising temperature reaches more than 130ºC, before cooling. Both sterilisation and pasteurisation using microwaves have yet to be widely used in the food industry, but they have the potential to become increasingly important.

18.1.4 Effect on foods

Microwaves and radio frequency energy have no direct effect on micro-organisms, in contrast with ionising radiation (Chapter 8), and all changes are caused by heat alone. In pasteurisation and blanching applications, the high rates of heat transfer for a specified level of microbial or enzyme destruction result in reduced losses of heat-sensitive nutrients (for example there is no loss of carotene in microwave-blanched carrots, compared with 28% loss by steam blanching and 45% loss by water blanching (von Loesecke, 1942)). However, the results for some foods are highly variable and, for these, microwave heating offers no nutritional advantage over steaming. Changes to foods in other types of processing (frying, baking dehydration, etc.) are described in the relevant chapters. The effects of microwave cooking on nutrient retention in domestic and catering applications are described by Klein (1982) and Lachance (1975).

18.2 Ohmic heating

Also termed ‘resistance heating’ or ‘electroheating’, this is a more recent development in which an alternating electric current is passed through a food, and the electrical resistance of the food causes the power to be translated directly into heat. As the food is an electrical component of the heater, it is essential that its electrical properties (its resistance) are matched to the capacity of the heater.

The concept of direct heating in this way is not new, but it has been developed into a commercial process during the last 15 years by the APV Baker company, using a licensed design by EA Technology. The process can be used for UHT sterilisation of foods, and especially those that contain large particles (up to 2.5 cm) that are difficult to sterilise by other means (see Chapter 12). It is now in commercial use in Europe, the USA and Japan for:

- aseptic processing of high added-value ready meals, stored at ambient temperature
- pasteurisation of particulate foods for hot filling
- pre-heating products before canning
- high added-value prepared meals, distributed at chill temperatures (Fryer, 1995).

Ohmic heating is more efficient than microwave heating because nearly all of the energy enters the food as heat. Another important difference is that microwave and radio frequency heating have a finite depth of penetration into a food whereas ohmic heating has no such limitation. However, microwave heating requires no contact with the food, whereas ohmic heating requires electrodes to be in good contact. In practice the food should be liquid or have sufficient liquid with particulate foods to allow good contact and to pump the product through the heater.

The advantages of ohmic heating are as follows:

- the food is heated rapidly ($1^{\circ}C\,s^{-1}$) at the same rate throughout and the absence of temperature gradients results in even heating of solids and liquids if their resistances are the same
- heat transfer coefficients do not limit the rate of heating
- temperatures sufficient for UHT processing can be achieved
- there are no hot surfaces for heat transfer, as in conventional heating, and therefore no risk of surface fouling or burning of the product which results in reduced frequency of cleaning
- heat sensitive foods or food components are not damaged by localised over-heating
- liquids containing particles can be processed and are not subject to shearing forces that are found in, for example, scraped surface heat exchangers (Chapter 12)
- it is suitable for viscous liquids because heating is uniform and does not have the problems associated with poor convection in these materials
- energy conversion efficiencies are very high (>90%)
- lower capital cost than microwave heating
- suitable for continuous processing.

Further details are given by Sastry (1994) and Rahman (1999).

18.2.1 Theory

Foods that contain water and ionic salts are capable of conducting electricity but they also have a resistance which generates heat when an electric current is passed through them. The electrical resistance of a food is the most important factor in determining how quickly it will heat. Conductivity measurements are therefore made in product formulation, process control and quality assurance for all foods that are heated electrically. Electrical resistance of a food is measured using a multimeter connected to a conductivity cell. The measured resistance is converted to conductivity using:

$$\sigma = (1/R)(L/A) \qquad 18.4$$

Table 18.2 Electrical conductivity of selected foods at 19ºC

Food	Electrical conductivity ($S\,m^{-1}$)
1 Potato	0.037
2 Carrot	0.041
3 Pea	0.17
4 Beef	0.42
5 Starch solution (5.5%)	
(a) with 0.2% salt	0.34
(b) with 0.55% salt	1.3
(c) with 2% salt	4.3

From Kim *et al.* (1996).

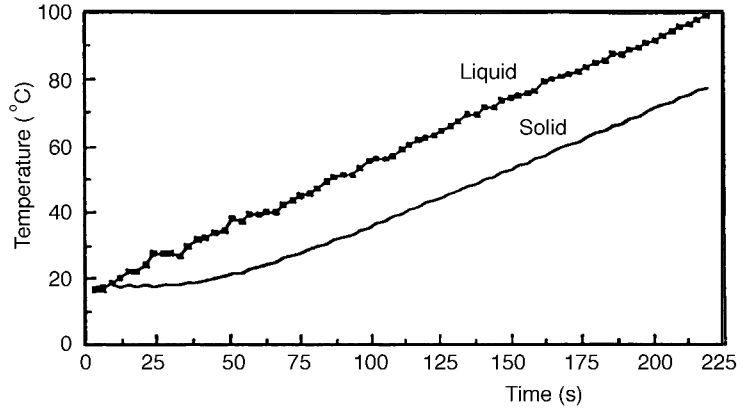
where σ ($S\,m^{-1}$) = product conductivity, R (ohms) = measured resistance, L (m) = length of the cell and A (m^2) = area of the cell.

In composite foods, the conductivity of the particle is measured by difference (i.e. the product conductivity minus the carrier medium conductivity). Data on electrical conductivity of foods (Table 18.2) is as yet relatively scarce, but has a much greater range than thermal conductivity (Chapter 1, Table 1.5). It can vary from $10^8\,S\,m^{-1}$ for copper to $10^{-8}\,S\,m^{-1}$ for an insulating material such as wood. Electrical conductivity is also expressed as the inverse: *specific electrical resistance*. Unlike metals, where resistance increases with temperature, the electrical resistance of a food falls by a factor of 2 to 3 over a temperature rise of 120ºC (Reznick, 1996). It can also vary in different directions (e.g. parallel to, or across, a cellular structure), and can change if the structure changes (e.g. gelatinisation of starch, cell rupture or air removal after blanching).

It can be seen in Table 18.2 that the conductivity of vegetables is lower than for muscle tissue, and this in turn is considerably lower than for a sauce or gravy. The salt content of a gravy is typically 0.6–1% and from the data (5b) in Table 18.2 the conductivity of the beef is about a third of that of the gravy. This has important implications for UHT processing of particles (Section 18.2.2): if in a two-component food, consisting of a liquid and particles, the particles have a lower electrical resistance, they are heated at a higher rate. This is not possible in conventional heating due to the lower thermal conductivity of solid foods, which slows heat penetration to the centre of the pieces (Chapter 1), (Fig. 18.5). Ohmic heating can therefore be used to heat sterilise particulate foods under UHT conditions without causing heat damage to the liquid carrier or over-cooking of the outside of particles. Furthermore, the lack of agitation in the heater maintains the integrity of particles and it is possible to process large particles (up to 2.5 cm) that would be damaged in conventional equipment.

The most important feature of ohmic heating is the rate of heat generation, which in addition to the electrical resistance of the product, depends on the specific heat capacities of each component, the way that food flows through the equipment and its residence time in the heater. If the two components have similar resistances, the lower moisture (solid portion) heats faster than the carrier liquid. However, the calculation of heat transfer is extremely complex, involving the simultaneous solution of equations for electrical, thermal and fluid flow fields and is beyond the scope of this book. Details are given in Fryer (1995) and Sastry and Li (1996). A simplified theory of heating is given below.

The resistance in an ohmic heater depends on the specific resistance of the product, and the geometry of the heater:



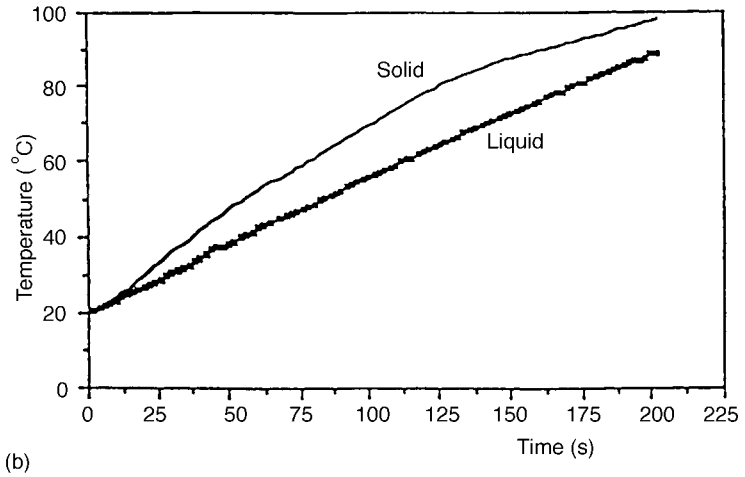


Fig. 18.5 Heat penetration into solid pieces of food by (a) conventional heating and (b) ohmic heating.
(Adapted from Fryer (1995).)

$$R = (R_s x)/A \qquad 18.5$$

where R (ohms) = total resistance of the heater, R_s (ohms m^{-1}) = specific resistance of the product, x (m) = distance between the electrodes and A (m^2) = area of the electrodes.

The resistance determines the current that is generated in the product:

$$R = \frac{V}{I} \qquad 18.6$$

where V (volts) = voltage applied and I (amps) = current.

The available 3-phase power sources in most countries have 220–240 volts per phase at a frequency of 50 Hz and to make the best use of the power, the geometry of the heater and the resistance of the product have to be carefully matched. If the resistance is too high, the current will be too low at maximum voltage. Conversely, if the resistance is too low, the maximum limiting current will be reached at a low voltage and again the heating power will be too low.

Every product has a critical current density and if this is exceeded, there is likely to be arcing (or flash-over) in the heater. The current density is found by:

$$I_d = I/A \quad (18.7)$$

where I_d (amps cm^{-2}) = current density.

The minimum area for the electrodes can therefore be calculated once the limiting current density and maximum available current are known. As resistance is determined in part by the area of the electrodes (equation 18.5), the distance between the electrodes can be calculated. It is important to recognise that the design of the heater is tailored to products that have similar specific electrical resistances and it cannot be used for other products without modification.

The rate of heating is found using equation (18.8):

$$Q = m.C_p.\Delta\theta \quad (18.8)$$

and the power by

$$P = V\,I \quad (18.9)$$

and

$$P = R\,I^2 \quad (18.10)$$

Assuming that heat losses are negligible, the temperature rise in a heater is calculated using

$$\Delta\theta = \frac{V^2\sigma_a A}{xmc_p} \quad (18.11)$$

where $\Delta\theta$ (ºC) = temperature rise, σ_a ($S\,m^{-1}$) = average product conductivity throughout temperature rise, A (m^2) = tube cross-sectional area, x (m) = distance between electrodes, M ($kg\,s^{-1}$) = mass flowrate and c_p ($J\,kg^{-1}\,{}^oC^{-1}$) = specific heat capacity of the product.

18.2.2 Equipment and applications

As described in Section 18.2.1, the design of ohmic heaters must include the electrical properties of the specific product to be heated, because the product itself is an electrical component. This concept is only found elsewhere in radio frequency heating and requires more specific design considerations than those needed when choosing other types of heat exchangers. Ohmic heaters should therefore be tailored to a specific application and the following factors taken into account:

- the type of product (electrical resistance and change in resistance over the expected temperature rise)
- flowrate
- temperature rise (determines the power requirement)
- heating rate required
- holding time required.

To be commercially successful, ohmic heaters must:

- have effective control of heating and flow rates
- be cost effective

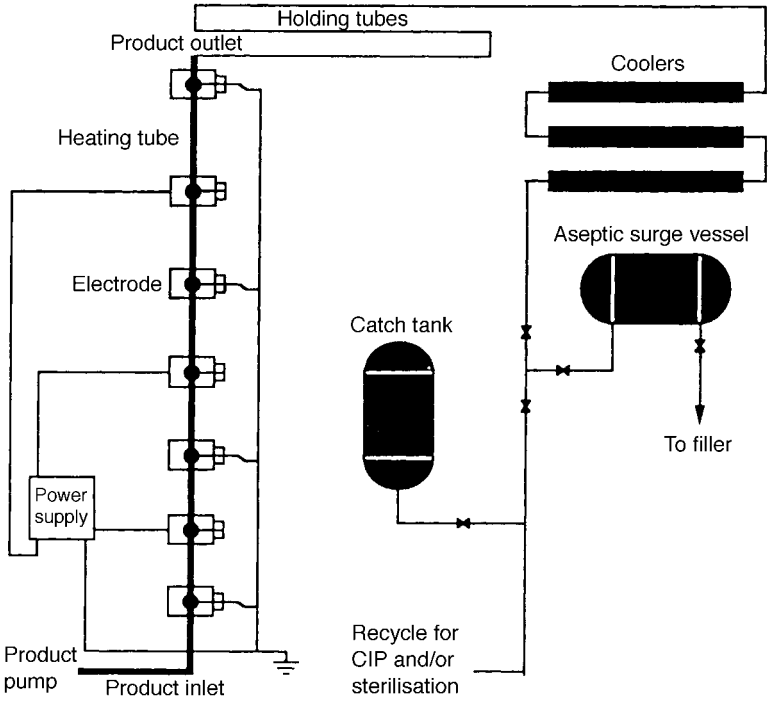


Fig. 18.6 Flowsheet for ohmic heating system.
(After Parrott (1992).)

- allow aseptic processing and packaging
- have an electrical design that avoids electrolysis or product scorching.

Early designs used DC power, which caused electrolysis (corrosion of electrodes and product contamination) and also had expensive electrodes. The use of mains power supply at 50 Hz reduces the risk of electrolysis and minimises the complexity and cost. Alternatively, higher frequencies (>100 kHz) or carbon electrodes may be used to reduce electrolysis. The layout of the APV Baker ohmic heating system is shown in Fig. 18.6.

Pre-treatments of solid components include:

- pre-heating in the carrier liquid to equilibrate resistances
- blanching pasta for moisture absorption
- heating the carrier liquid to pre-gelatinise starch
- heating to melt and expel fats
- stabilisation of sauces by homogenisation, especially dairy sauces or others that contain fats and heat sensitive proteins
- blanching vegetables to expel air and/or to denature enzymes
- enzymic marinades to soften texture and enhance flavour of meats
- soaking in acids or salts to alter the electrical resistance of particles
- sautéing to improve appearance of meat particles (Zoltai and Swearingen, 1996).

Ohmic heating has been used to process various combinations of meats, vegetables, pasta and fruits when accompanied by a suitable carrier liquid. A variety of shapes, including cubes, discs, spheres, rods and twists have been processed (Zoltai and

Swearingen, 1996). In operation, the bulk of the carrier liquid is sterilised by conventional plate or tubular heat exchangers (Chapter 12) and then injected into the particle stream as it leaves the holding tube. This has the advantage of reducing the capital and operating costs for a given throughput and allows a small amount of carrier liquid to be used to suspend the particles, thus improving process efficiency (Dinnage, 1990). Ohmic heating costs were found by Allen *et al.* (1996) to be comparable to those for freezing and retort processing of low acid products.

Food is pumped up through a vertical tube containing a series of electrodes where it is heated to process temperature. The stainless steel cantilever electrodes (supported from one side) are contained in a PTFE housing and fit across the tube. An alternating current from a 3-phase supply flows between the electrodes and through the food as it moves along the tube. The tube sections are made from stainless steel, lined with an insulating plastic such as polyvinyidene fluoride (PVDF), polyether ether ketone (PEEK) or glass. The system is designed to maintain the same impedance in each section between the electrodes, and the tubes therefore increase in length between inlet and outlet because the electrical conductivity of the food increases as it is heated. Typically, an overall tube dimension of 0.3 cm internal diameter and 30 cm length could heat several hundred litres per hour, whereas a tube of 2.5 cm diameter and 2 m length could heat several thousand litres per hour (Reznick, 1996). Commercial equipment is available with power outputs of 75 and 300 kW, which correspond to throughputs of approximately 750 and 3000 $kg\,h^{-1}$ respectively (Fryer, 1995). The process is automatically controlled via a feed-forward system (Chapter 2), which monitors inlet temperature, product flow rate and specific heat capacity and continuously adjusts the power required to heat the product (Dinnage, 1990).

The almost complete absence of fouling in ohmic heaters means that after one product has been processed, the plant is flushed through with a base sauce and the next product is introduced. At the end of processing, the plant is flushed with a cleaning solution.

In conventional heaters, turbulence is needed to create mixing of the product and maintain maximum temperature gradients and heat transfer coefficients (Chapter 1, Section 1.3). In ohmic heating, the electric current flows through the product at the speed of light and there are no temperature gradients since the temperature is uniform across the cross-section of flow. The flowrate of product is negligible compared to the velocity of the electric current, but if the flowrate is not uniform across the cross-sectional area, the very high rates of heating mean that slower moving food will become considerably hotter. It is therefore important to ensure that uniform (or 'plug') flow conditions are maintained in the heater. Kim *et al.* (1996) give details of experimental studies which confirm that this takes place. Similarly, the type of pump that is used should provide a continuous flow of material without pulses, as these would lead to increased holding times in the tube and uneven heating. A high pressure is maintained in the heater (up to 4 bar for UHT processing at 140ºC) to prevent the product from boiling. Food then passes from the heater to a holding tube where it is held for sufficient time to ensure sterility and is then cooled and aseptically packaged (also Chapter 12).

The process is suitable for particulate foods that contain up to about 60% solids. In contrast to conventional UHT processing of particulate foods, where the liquid component is an important medium for heat transfer into the particles, in ohmic heating a high solids content is desirable for two reasons: faster heating of low-conductivity particles than the carrier liquid and plug flow in the heater tubes. High solids concentrations can be processed if the particles are pliable and small, or their geometry is varied to reduce the void spaces between particles. Lower concentrations require a higher

viscosity carrier liquid to keep the particles in suspension. The density of the particles should also be matched to the carrier liquid: if particles are too dense or the liquid is not sufficiently viscous, the particles will sink in the system and be over-processed. Conversely, if the particles are too light they will float and this leads to variable product composition and the risk of under-processing. It is almost impossible to determine the residence time or heating profiles of particles that float or sink. The viscosity of the fluid (sauce or gravy) should therefore be carefully controlled and for example, pre-gelatinised starches should be used to prevent viscosity changes during processing.

In order for ohmic UHT processing of particulate foods to be accepted by the regulatory authorities, it is necessary to ensure that the coldest part of the slowest heating particle in the food has received sufficient heat to ensure sterility (Chapter 1, Section 1.4.5 and Chapter 12). It is not easy to measure heat penetration into particles, whereas it is relatively easy to measure the temperature of the carrier liquid. The process must therefore demonstrate that solid particles are heated to an equal or greater extent than the liquid when they enter the holding tube. By adjustment of the electrical properties of each component (e.g. by control of salt content in the formulation) it is possible to ensure that this takes place for homogenous particles (Fig. 18.5), but data is not yet available for non-homogenous particles (e.g. fatty meat pieces) which have variable electrical resistance. The situation is made more complex when a batch of food is held before processing and, for example, salt leaches out of the particles into the surrounding sauce. This results in changes to the electrical resistance of both components and hence their rate of heating. Furthermore, the presence of fats and other poorly conductive materials means that particles will heat mostly by conduction and a cold spot will be created within the particle (Larkin and Spinak, 1996). It is important that there is no accidental inclusion of either highly conducting materials, or more likely insulating materials such as pieces of bone, fat, nuts or ice in a food, because neither will be heated. If this happens, the surrounding food may also be under-processed.

Other factors that need to be defined include:

- size and shape of particle pieces
- moisture content of solids
- solids/liquid ratio
- viscosity of liquid component
- amount and type of electrolytes
- pH
- specific heat
- thermal conductivity.

Additionally, the effect of processing on the above factors needs to be determined to detect whether they change and hence alter the heating characteristics of the product. Any changes to ingredients that are made to take account of changing consumer tastes or cost/availability should be tested to determine the effects on heating characteristics (Larkin and Spinak, 1996).

18.3 Infrared heating

18.3.1 Theory

Infrared energy is electromagnetic radiation (Fig. 18.1) which is emitted by hot objects. When it is absorbed, the radiation gives up its energy to heat materials. The rate of heat transfer depends on:

- the surface temperatures of the heating and receiving materials
- the surface properties of the two materials
- the shapes of the emitting and receiving bodies.

The amount of heat emitted from a *perfect radiator* (termed a *black body*) is calculated using the Stefan–Boltzmann equation:

$$Q = \sigma A T^4 \qquad 18.12$$

where Q ($\mathrm{J\,s^{-1}}$) = rate of heat emission, s = 5.7×10^{-8} ($\mathrm{J\,s^{-1}\,m^{-2}\,K^{-4}}$) the Stefan-Boltzmann constant, A ($\mathrm{m^2}$) = surface area and T (K = ºC + 273) = absolute temperature. This equation is also used for a *perfect absorber* of radiation, again known as a *black body*. However, radiant heaters are not perfect radiators and foods are not perfect absorbers, although they do emit and absorb a constant fraction of the theoretical maximum. To take account of this, the concept of *grey bodies* is used, and the Stefan–Boltzmann equation is modified to:

$$Q = \varepsilon \sigma A T^4 \qquad 18.13$$

where ϵ = emissivity of the grey body (a number from 0 to 1) (Table 18.3). Emissivity varies with the temperature of the grey body and the wavelength of the radiation emitted.

The amount of absorbed energy, and hence the degree of heating, varies from zero to complete absorption. This is determined by the components of the food, which absorb radiation to different extents, and the wavelength of the radiated energy. Some of this radiation is absorbed and some is reflected back out of the food. The amount of radiation absorbed by a grey body is termed the *absorptivity* (α) and is numerically equal to the emissivity (Table 18.3). Radiation which is not absorbed is reflected and this is expressed as the *reflectivity* ($1 - \alpha$). There are two types of reflection: that which takes place at the surface of the food and that which takes place after radiation enters the food structure and becomes diffuse due to scattering. Surface reflection produces the gloss observed on polished materials whereas body reflection produces the colours and patterns of a material.

The wavelength of infrared radiation is determined by the temperature of the source. Higher temperatures produce shorter wavelengths which have a greater depth of penetration. The net rate of heat transfer to a food therefore equals the rate of absorption minus the rate of emission:

$$Q = \varepsilon \sigma A (T_1^4 - T_2^4) \qquad 18.14$$

where T_1 (K) = temperature of emitter and T_2 (K) = temperature of absorber.

Table 18.3 Approximate emissivities of materials in food processing

Material	Emissivity
Burnt toast	1.00
Dough	0.85
Water	0.955
Ice	0.97
Lean beef	0.74
Beef fat	0.78
White paper	0.9
Painted metal or wood	0.9
Unpolished metal	0.7–0.25
Polished metal	< 0.05

From Earle (1983) and Lewis (1990).

Sample problem 18.1
An 8 kW oven has a hearth area of $4\,m^2$ and operates at 210ºC. It is loaded with two batches of bread dough in baking tins; 150 loaves on the first batch and 120 loaves on the second batch. The surface of each loaf measures 12 cm × 20 cm. Assuming that the emissivity of dough is 0.85, that the dough bakes at 100ºC, and that 90% of the heat is transmitted in the form of radiant energy, calculate the efficiency of energy use (as the percentage of the supplied radiant energy which is absorbed by the food) for each batch.

Solution to Sample problem 18.1
In the first batch,

$$\text{area of dough} = 150(0.2 \times 0.12) = 3.6\,m^2$$

From equation (18.14)

$$Q = 3.6 \times 0.85\,(5.73 \times 10^{-8})\,(483^4 - 373^4) = 6145.6\,W$$

In the second batch,

$$\text{area of dough} = 120(0.2 \times 0.12) = 2.88\,m^2$$

and

$$Q = 2.88 \times 0.85\,(5.73 \times 10^{-8})\,(483^4 - 373^4) = 4916\,W$$

Thus, for the first batch,

$$\text{efficiency} = \frac{6145.6}{8 \times 0.9} = 85\%$$

and, for the second batch,

$$\text{efficiency} = \frac{4916}{8 \times 0.9} = 68\%$$

18.3.2 Equipment

Types of radiant heaters include flat or tubular metal heaters, ceramic heaters, and quartz or halogen tubes fitted with electric filaments (Table 18.4).

The main commercial application of radiant energy is in drying low-moisture foods (for example breadcrumbs, cocoa, flours, grains, malt, pasta products and tea) and in baking or roasting ovens (Chapter 16). Products pass through a tunnel, beneath banks of radiant heaters, on a conveyor (Ginzberg, 1969). It is not, however, widely used as a single source of energy for drying larger pieces of food because of the limited depth of penetration. Radiant energy is also used in vacuum band driers and cabinet driers (Chapter 15), in accelerated freeze driers (Chapter 22), in some

Table 18.4 Infrared emitter characteristics

Type of emitter	Maximum running temperature (°C)	Maximum intensity ($kW\,m^{-2}$)	Maximum process temperature (°C)	Radiant heat (%)	Convection heat (%)	Heating–cooling time (s)	Expected life
Short wavelength							
Heat lamp	2200	10	300	75	25	1	5000 h
IR gun	2300	2	1600	98	2	1	–
Quartz tube	2200	80	600	80	20	1	5000 h
Medium wavelength							
Quartz tube	950	60	500	55	45	30	Years
Long wavelength							
Element	800	40	500	50	50	< 120	Years
Ceramic	700	40	400	50	50	< 120	Years

From Anon. (1981).

domestic microwave ovens to brown the surface of foods; and to heat-shrink packaging film (Chapter 25).

18.3.3 Effect on foods

The rapid surface heating of foods seals in moisture and flavour or aroma compounds. Changes to surface components of foods are similar to those that occur during baking and are described in Chapter 16.

18.4 Acknowledgements

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Table III

Most Probable Number (MPN) of Bacteria Per 100 g (ml) of Test Material Using 5 Tubes With 10, 1 and 0.1 ml or g of Test Material

10;1;0,1	MPN	10;1;0,1	MPN	10;1;0,1	MPN	10;1;0,1	MPN	10;1;0,1	MPN	10;1;0,1	MPN
000	<1.8	100	2	200	4.5	300	7.8	400	13	500	23
001	1.8	101	4	201	6.8	301	11	401	17	501	31
002	3.6	102	6	202	9.1	302	13	402	21	502	43
003	5.4	103	8	203	12	303	16	403	25	503	58
004	7.2	104	10	204	14	304	20	404	30	504	76
005	9	105	12	205	16	305	23	405	36	505	95
010	1.8	110	4	210	6.8	310	11	410	17	510	33
011	3.6	111	6.1	211	9.2	311	14	411	21	511	46
012	5.5	112	8.1	212	12	312	17	412	26	512	64
013	7.3	113	10	213	14	313	20	413	31	513	84
014	9.1	114	12	214	17	314	23	414	36	514	110
015	11	115	14	215	19	315	27	415	42	515	130
020	3.7	120	6.1	220	9.3	320	14	420	22	520	49
021	5.5	121	8.2	221	12	321	17	421	26	521	70
022	7.4	122	10	222	14	322	20	422	32	522	95
023	9.2	123	12	223	17	323	24	423	38	523	120
024	11	124	15	224	19	324	27	424	44	524	150
025	13	125	17	225	22	325	31	425	50	525	180
030	5.6	130	8.3	230	12	330	17	430	27	530	79
031	7.4	131	10	231	14	331	21	431	33	531	110
032	9.3	132	13	232	17	332	24	432	39	532	140
033	11	133	15	233	20	333	28	433	45	533	180
034	13	134	17	234	22	334	31	434	52	534	210
035	15	135	19	235	25	335	35	435	59	535	250
040	7.5	140	11	240	15	340	21	440	34	540	130
041	9.4	141	13	241	17	341	24	441	40	541	170
042	11	142	15	242	20	342	28	442	47	542	220
043	13	143	17	243	23	343	32	443	54	543	280
044	15	144	19	244	25	344	36	444	62	544	350
045	17	145	22	245	28	345	40	445	69	545	440
050	9.4	150	13	250	17	350	25	450	41	550	240
051	11	151	15	251	20	351	29	451	48	551	350
052	13	152	17	252	17	352	32	452	56	552	540
053	15	153	19	253	26	353	37	453	64	553	920
054	17	154	22	254	29	354	41	454	72	554	1600
055	19	155	24	255	32	355	45	455	81	555	>1600

C. Enumeration of yeasts and moulds in foods

1. Application

This method is applicable to the enumeration of viable yeasts and moulds in foods and food ingredients It may also be used to confirm the viability of apparent yeast and mould material scraped from food plant equipment and the manufacturing environment.

2. Principle

In the past, acidified media were used to enumerate yeasts and moulds in foods. Such media are now recognized as inferior to antibiotic supplemented media that are formulated to suppress bacterial colony development, enhance resuscitation of injured fungi, and minimize precipitation of food particles.

A medium, containing (a) adequate nutrients for growth of most yeasts and moulds and (b) antibiotics for inhibition of most bacteria, is inoculated with a given quantity of the product or with scrapings from equipment or the manufacturing environment. It is incubated at 22-25^{o}C for 3-5 days. Colonies appearing on the medium are then counted and/or examined. The method described here is a "general purpose" method and may not be suitable for detection of yeasts and moulds adapted to certain foods, e.g., foods of very low water activity.

3. Defination of terms

3.1. Scrapings: Suspected yeast and mould material scraped from food plant equipment and the manufacturing environment.

3.2. Xerophilic: Moulds capable of growing at reduced water activity (a_w). (Yeasts preferring reduced a_w are also sometimes referred to as xerophilic.) (7.5)

3.3. Osmophilic: Yeasts preferring reduced a_w for growth.

Precautions

Some yeasts and moulds can be infectious or can cause allergic responses, therefore, it is important to be fairly cautious when working with fungi. Ideally, plates should be held in incubators, not in an open room. Plate lids should generally only be removed for procedures such as the preparation of a slide for microscopic examination.

Flamed needles should be cooled before making transfers to avoid dispersal of conidia and other cells. Cultures should never be smelled.

4. Materials and special equipment

The following media and reagents (1-8) are commercially available and are to be prepared and sterilized according to the manufacturer's instructions. and reference 7.3 for the formula of individual media.

Note: If the analyst uses any variations of the media listed here (either product that is commercially available or made from scratch), it is the responsibility of the analyst or Laboratory Supervisor to ensure equivalency.

Enumeration of yeasts and moulds in foods (not specified below)

These agars are suitable for foods where the a_W is above 0.95, such as fresh foods (fruit, vegetables, meat and dairy).

1) Dichloran rose bengal chloramphenicol agar (DRBC)

2) Plate count agar with chloramphenicol (PCA-C)

3) Potato dextrose agar with chloramphenicol (PDA-C)

4) Potato dextrose salt agar with chloramphenicol (PDSA-C) (for analysis of 'spreader' moulds)

Enumeration of xerophilic yeasts and moulds in grains, flours, nuts, and spices

5) Dichloran-glycerol DG 18 agar (DG-18)

Enumeration of xerophilic yeasts and moulds in jams, jellies, fruit concentrates, and dried fruits

6) 20% sucrose (diluent additive for osmophiles, see 6.3.1)

7) Malt extract agar containing 50% (w/w) sucrose

Other:

8) Peptone water (0.1%) (PW)

9) 2% sodium citrate tempered to 45°C (diluent for high fat foods, such as cheese) (optional)

10) 1N HCl and 1N NaOH

11) Gram stain solutions

12) Stomacher, blender or equivalent

13) pH meter or paper capable of distinguishing to 0.3 to 0.5 pH units within a range of 5.0 to 8.0

14) Light microscope

15) Colony counting device (optional)

16) Incubator (darkened) capable of maintaining 22 to 25°C, 55°C waterbath (and 45°C waterbath if sodium citrateistobeused).

5. Procedure

Each sample unit shall be analyzed individually. The test shall be carried out in accordance with the following instructions:

5.1. Handling of Sample Units and Scrapings

5.1.1. During storage and transport, the following shall apply: with the exception of shelf-stable products, keep the sample units refrigerated (0-5°C). Sample units of frozen products shall be kept frozen.

5.1.2. Thaw frozen samples in a refrigerator or under time and temperature conditions which prevent microbial growth or death.

5.1.3. Analyze the sample units as soon as possible after receipt at the laboratory.

5.2. Preparation of Medium

5.2.1. Prepare the appropriate media for the analysis being carried out (see Section 5).

NOTE: DRBC agar should not be exposed to light, since photo-degradation of rose bengal produces compounds that are toxic to fungi.

5.2.2. Temper melted agar in a 55°C waterbath, ensuring that the water level is 1 cm above the level of the medium in the bottles.

5.2.3. Clean surface of working area with a suitable disinfectant.

5.2.4. Mark clearly the duplicate petri plates identifying sample, sample unit, dilution and date of inoculation.

5.3. Preparation of Dilutions

5.3.1. Prepare 0.1% peptone water as diluent. An appropriate solute, such as 20% sucrose, should be added to the diluent when enumerating osmophiles in foods such as syrups and fruit juice concentrates. In addition, a 2% solution of sodium citrate, pre-warmed to 45°C, can be used as diluent for high-fat foods such as cheese.

5.3.2. To ensure a representative analytical portion, agitate liquid or free flowing materials until the contents are homogeneous. If the sample unit is a solid, obtain the analytical unit by taking a portion from several locations within the sample unit.

5.3.3. Some degree of soaking may be beneficial for the recovery of yeasts and moulds from dried or intermediate-moisture foods. Soaking may allow for the repair of sub-lethally damaged cells (resuscitation). Rehydrate dried foods for 1 h with an equal amount of distilled water or peptone water and store at room temperature.

5.3.4. Prepare a 1:10 dilution of the food by aseptically blending 25 g or mL (the analytical unit) into 225 mL of the required diluent, as indicated in Table I. If a sample size other than 25 g or mL is used, maintain the 1:10 sample to dilution ratio, such as 11 (10) g or mL into 99 (90) mL.

NOTE: Weight or volume in brackets indicates alternate procedure for making dilutions.

5.3.5. Stomach, blend or shake according to the type of food as indicated in Table 1.

Blend or stomach for the minimum time required to produce a homogeneous suspension. To prevent over-heating, blending time should not exceed 2.5 min. With foods that tend to foam, use blender at low speed and remove aliquot from below liquid/foam interface.

5.3.6. Verify the pH of the suspension. If the pH is not between 5.5 and 7.5, adjust the pH to 7.0 with a sterile solution of 1N NaOH or 1N HCl.

5.3.7. If the 1:10 dilution is prepared in a dilution bottle, it should be mixed by shaking the bottle 25 times through a 30 cm arc in approximately 7 sec.

5.3.8. Prepare succeeding decimal dilutions as required, using a separate sterile pipette for making each transfer.

5.3.9. Because mould propagules may settle out within a few minutes, it is important to shake all dilutions (as in 5.3.7) immediately prior to making transfers to ensure uniform distribution of the microorganisms present.

5.4. Plating

5.4.1 Agitate each dilution bottle to resuspend material that may have settled out during preparation.

5.4.2 Moulds should be enumerated by a surface spread-plate technique rather than with pour plates. This technique provides maximal exposure of the cells to atmospheric oxygen and avoids heat stress from molten agar. Agar spread plates should be dried overnight before being inoculated. Spread 0.1 mL onto duplicate plates (see Section 5 for appropriate plating media)

5.4.3 For determination of viability of suspected yeast and mould material from food plant equipment and the manufacturing environment, aseptically tease the scrapings apart and distribute the pieces over the surface of solidified medium.

5.5. Incubation

Incubate plates undisturbed in an upright position at 22 to 25^{o}C for 3-5 days. Incubate plates in the dark. Normally, count colonies on plates after 5 days. Examine on the third day and if mould colonies are numerous, count them and then count again on the fifth day, if possible. Handle the plates as little as possible when counting on day 3 so spores will not be dislodged, which may result in secondary growth

5.6. Counting Colonies and Examining Growth

5.6.1. Count colonies, distinguishing, if required, yeast colonies from mould colonies, according to their colonial morphology. Microscopic examination with crystal violet stained smears may be necessary to distinguish yeast colonies from some bacterial colonies that may look like yeast.

5.6.2. If possible, select plates with 10-150 colonies. Determine the identity of pin-point colonies microscopically. If counts do not fall within this range, select plates that fall nearest to the 10-150 range. If the mycoflora consists primarily of moulds, the lower population range is selected; if primarily yeast colonies, the upper limit is counted.

Alternatively,

5.6.3. If plates contain colonies which spread, select a representative portion of the plates free from spreaders, if possible, and count colonies in this area. The total count of the whole plate is estimated by multiplying the count for the representative area by the reciprocal of the fraction of the plate counted, e.g., 30 colonies counted on 1/4 of the area of the plate; count for the whole plate: 30 x 4 = 120 colonies. Results are expressed as an estimated count.

5.6.4. Wet mounts and gram stains of several diverse types of cells per sample should be examined to confirm that bacteria are not present. Yeast cells and asexual mould spores are generally gram-positive, whereas mould mycelia are gram-negative.

5.7. Differentiation of Colonies from Interfering Particles

5.7.1. Food particles such as meat, milk powder, etc., often interfere with the enumeration of colonies. This can be eliminated by making one extra plate of each dilution containing interfering particles, and holding it under refrigeration as a control for comparison during counting.

5.8. Recording Results

5.8.1. Calculate the average count (arithmetic mean) of the duplicate plates, following the examples in Table II: Standard Methods for the Examination of Dairy Products.

5.8.2. Avoid creating erroneous ideas of precision and accuracy when computing counts (Table II). Round-off counts to two significant figures and record only the first two left hand digits.

5.8.3. If the lowest dilution plated shows no colonies, the recorded value will be the lowest average obtainable with a given volume plated onto a given set of replicate plates preceded by a "less than" (<) sign, e.g., for 1 mL and a set of duplicate plates (1 mL/plate), the value is <0.5. (The lowest possible average with one colony on one of the two duplicate plates is: 1+0/2 = 0.5).

This value is for a 10^0 dilution (Dilution Factor = 1). For other dilutions, the numerical value of 0.5 must be multiplied by the reciprocal of the dilution, i.e., the Dilution Factor.

E.g. $1/10^{-1} = 10$.

5.8.4. To compute the yeast and mould count, use the formula: N = A x D, where N is the number of colonies per g (mL) of product, A is the average count per plate, and D is the respective dilution factor

TABLE I
Preparation of Initial Dilution

Type of food	Preparation*	Treatment
Liquids		
milk, water, juice, etc.	pipette directly into peptone water diluent	shake
Viscous liquids	Weigh into peptone water diluent	shake
Solids		
Water soluble solids	Weigh into peptone water diluent	shake
Powder, meats	Weigh into peptone water diluent	stomach or blend
all cheese	Weigh into previously warmed 45°C 2% aqueous sodium citrate ($NA_3C_6H_5O_7$-$2H_2O$)	stomach or blend
Spices	Weigh into peptone water diluent	shake
shellfish, fish products	Weigh into peptone water diluent	stomach or blend

Sample may be added into an empty stomacher bag, blender jar or dilution bottle and the diluent added prior to mixing.

TABLE II
Examples for Recording Results

Examples of the average number of colonies	Dilution	Report as no. of yeasts and moulds per g (mL)
count between 10-150, e.g., 144	1:1000	140,000
counts higher than 150, e.g., 440	Highest dilution 1:1000	440,000 E*
counts lower than 15, e.g., 10	Lowest dilution 1:1000	10,000 E
no count	Lowest dilution 1:1000	<500

* E is the estimated count