7 Heat Treatment of Milk

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7.1 Introduction

The aim of this chapter is to communicate the underlying principles for producing heat-treated milk which is safe and of high quality, based on many years of experience which has been gained from teaching, research and troubleshooting.

Although a small amount of milk is still sold as 'untreated' or raw, the two main heat treatments used for milk sold in the retail sector are pasteurisation and sterilisation. Treatments somewhere between these are also being used for extending shelf life. The main aims of heat treatment are to reduce the microbial population, both pathogenic and spoilage, in raw milk to inactivate enzymes and to minimise chemical reactions and physical changes. An overview of the changes taking place when milk is heated is given by Walstra & Jenness (1984). Some important ones are a decrease in pH, precipitation of calcium phosphate, denaturation of whey proteins and interaction with casein, lactose isomerisation, Maillard browning and modifications to the casein micelle. The overall effect is to alter the sensory characteristics, i.e. overall appearance, colour, flavour and texture and the nutritional value as well as making it safe and improving its keeping quality.

Most of the milk destined for processing into dairy products is also heat treated in some form, although some cheeses are made from raw milk. One industrial process is thermisation, which involves heating milk at temperatures between 57 and 68°C for about 15 s. Another is preheating or forewarming, applied to milks prior to evaporation and powder production. Conditions can be as low as 72°C for low-heat powders and up to 90–95°C for 5–10 min for high-heat powders, although temperatures above 100°C for shorter times are also used.

Patterns of consumption and preferences for milk vary from one country to another. For example, in Great Britain in 2003, 92.9% of heat-treated milk for drinking was pasteurised, 1.4% (in-container) sterilised and 5.7% ultra-high temperature (UHT) treated (Anonymous, 2003a). In Australia, the corresponding figures for white milk are 91.9%, 0% and 8.1%, respectively. The balance is totally different in other European countries, and in some, such as France and Germany, UHT milk is the main milk product.

Going back about 50 years, only a limited number of products were available. These were mainly white milk, limited flavoured milks and some creams. Domestic refrigeration was not widespread and pasteurised milk stored in the larder would keep for only 24–48 h. Sterilised milk with its characteristic flavour and slightly brown colour was quite popular in the UK and powdered, evaporated and sweetened condensed milks were available. UHT milk was in its infancy and fermented milks were for the future. Heat treatment was on a small to medium scale.

Jumping forward to the twenty-first century, one big change is the scale of operation, with a move towards highly automated large-scale, energy-saving continuous processes. In terms of product availability, we are now spoilt for choice. Milk is standardised for both protein and fat: semi-skimmed milk at 1.5–1.8 g fat 100 g^{-1} is now popular, accounting for 57.3% of all liquid milk drunk in Great Britain in 2003, and skimmed milk at 0.1 g fat 100 g^{-1} provides a low-fat version. For those who prefer a richer fuller flavour, milk from Jersey and Guernsey cows and other rare breeds can be purchased; these no longer are said to contain 5 g fat 100 g^{-1}, but are now '95% fat-free'. There is a wide range of flavoured milks, and creams ranging from 12 to 55 g fat 100 g^{-1}, with textures ranging from thin coffee creams to very viscous spoonable dessert creams. Competing with cow's milk are milks from goat, sheep and buffalo, as well as specialty milks for cats and dogs.

The industry is rightly promoting the health benefits of components naturally present in milk, i.e. specific fat fractions, bioactive peptides, beneficial minerals, especially calcium and magnesium, or producing milks with a healthy image, for example fermented milks, lactose-reduced milk, melatonin milk and milks containing probiotic microorganisms, prebiotic compounds, plant sterols or fish oils. In many parts of the world, conditions are not conducive to producing fresh milk; hence reconstituted and recombined milk are produced. Some dairy companies are now also processing 'vegetable milks', based on extracts from soy, rice, sweet corn and other vegetables.

7.2 Milk composition

Although there are many sources of data for composition of milk and milk products (McCance & Widdowson (2002), these report average values, giving no indication of the variability of raw milk due to breed, diet, climate and stage of lactation. This should not be forgotten when processing milk or when using data from the literature. The complexity and changing composition of raw milk pose key challenges.

Milk is an emulsion, containing fat globules in the range 1–10 microns in diameter, dispersed in an aqueous phase. Above 45°C, all this fat will be in the liquid phase; below this temperature, it will start to crystallise. This is not an instantaneous process and during crystallisation, latent heat will be released. The proteins in milk are divided into two fractions: (a) the casein fraction and (b) the whey protein fraction. The casein fraction is complex and exists in micelles with a size range of 30–300 nm. In the context of heat treatment, heat stability is very important and is influenced by several factors, particularly pH and ionic calcium.

The casein micelle is remarkably stable to heat, and good quality milk can withstand temperatures of 140°C for at least 10 min and often longer without coagulating. However, if the milk is not properly handled, its stability can deteriorate drastically. Some manifestations of poor heat stability are fouling or deposit formation on heat exchangers, sediment in milk and heat-induced thickening and coagulation. These problems tend to increase as the processing temperature increases, but are also dependent on raw milk quality.

In this context, a very important property is milk acidity, measured as pH or titratable acidity. Whereas pH is a direct measure of H^+activity, titratable acidity is a measure of buffering capacity between its own pH and that of the colour change (from colourless to red) in phenolphthalein, which is about 8.3. The pH of milk may influence many other aspects

related to quality, in particular, the colloidal stability of milk and other heat-induced reactions, such as Maillard browning and lactulose formation. Both microbial activity and microbial inactivation are also influenced by pH, as is enzyme activity. The pH of raw milk is usually between 6.6 and 6.7, but it can be outside this range – for example 6.40–6.89 (Tsioulpas *et al*., 2007a). Its exact value is influenced by its protein, mineral and acid contents. The pH of milk falls during heat treatment, but this is largely reversible on cooling. Walstra & Jenness (1984) illustrated that pH could fall to below 6.0, when the temperature exceeds 100°C. Another important determinant is ionic calcium, but its influence on heat stability is less well established, mainly because of difficulties in measuring it. Thus, the pH and ionic calcium in raw milk may be useful heat stability indicators, especially in sterilisation and UHT treatment of normal milk and in situations where milk is fortified with calcium or acidified.

Milk is a bland fluid with a characteristic creamy flavour. Because of this blandness, it is very susceptible to off-flavours; for example, a rancid flavour may develop due to excessive agitation of raw milk (Deeth & Fitz-Gerald, 2006). Raw milk from healthy animals has a very low microbial count, but it easily becomes contaminated with spoilage bacteria and perhaps some pathogenic microorganisms. These need to be inactivated and this is readily achieved by heat treatment. From the standpoint of the milk processor, raw milk composition and its microbial loading will vary from day to day.

7.3 Reaction kinetics

All thermal processes involve three distinct periods: a heating period, a holding period and a cooling period. In theory, all three periods may contribute to the reactions taking place, although in situations where heating and cooling are rapid, the holding period is the most significant. However, procedures are needed to evaluate each of these periods individually to determine the overall effect. One such example of this approach is offered by Browning *et al*. (2001).

The two reaction kinetic parameters of interest are the rate of reaction or inactivation at a constant temperature (e.g. D and k values), and the effect of temperature change on reaction rate (z and E values).

For pasteurisation processes, the range of interest is 60–80°C, and for sterilisation, from 100 to over 150°C. Chemical reaction rates are less temperature-sensitive than microbial inactivation rates. Thus, using heat treatment at higher temperatures for shorter times will result in less chemical damage occurring for an equivalent level of microbial inactivation. In practice, deviations from first order reaction kinetics are often encountered (Gould, 1989), as are deviations from the log–linear relationships between processing time and temperature discussed recently by Peleg (2006).

7.4 Principles of heat transfer

In thermal processing, the aim is to maximise the rate of heat transfer (Js^{-1} (W) or British thermal units (BTU) h^{-1}), i.e. to heat and then cool the product down as quickly as possible. This will improve the economics of the process and in many cases also lead to an improvement in product quality. Heating processes can be classified as direct or indirect. The most widely used is indirect heating, where the heat transfer fluid and the milk are

separated by a barrier; for in-container sterilisation this will be the wall of the bottle and for continuous processes, the heat exchanger plate or tube wall. In direct processes, steam is the heating medium and the steam comes into direct contact with the milk. Indirect heating also implies that the two fluids will not come into direct contact. It is important to ensure that this is the case, and the integrity of the barrier is a very important safety consideration, especially in the regeneration section where the heating medium is the hot heat-treated milk. The heating medium is usually saturated steam but hot water and hot air are sometimes used. At temperatures above 100°C, the steam and the hot water are above atmospheric pressure. For steam, there is a fixed relationship between its pressure and temperature, given by the steam tables (Lewis, 1990; Holdsworth, 1997). Thus, a steam pressure gauge will act indirectly as a second temperature-monitoring device. Discrepancies between temperature and pressure readings suggest that there may be some air in the steam or that the instruments are incorrect (Lewis & Heppell, 2000). Cooling is achieved using mains water, chilled water or glycol. Regeneration is used in continuous processes to further reduce energy utilisation. Heating can be by either batch or continuous processing. Section 7.13 gives a review of the main physical properties of fluid that influence heat transfer as well as some of the basic heat transfer equations.

7.5 Thermisation and tyndallisation

Thermisation is the mildest heat treatment given to milk. It is used to extend the keeping quality of raw milk when it is known that raw milk may be held chilled for some time, prior to being further processed. The aim is to reduce the growth of psychrotrophic bacteria, which may release heat-resistant proteases and lipases into the milk. These enzymes will not be totally inactivated during pasteurisation and may give rise to off-flavours if the milk is used for cheese or milk powders. Conditions used for thermisation are 57–68°C for 15 s, followed by refrigeration. Thermised raw milk can be stored at a maximum of 8°C for up to 3 days (IDF, 1984). The milk should also be phosphatase-positive in order to distinguish it from pasteurised milk, which is phosphatase-negative. It is usually followed later by pasteurisation or a more severe heat treatment.

Another thermal process, which has been investigated, is tyndallisation; it involves successive heat treatments in order to inactivate spores. According to Wilbey (2002), Tyndall in 1877 suggested that if a medium was heated at 100°C for 3 min on 3 successive days, first the vegetative cells would be killed and the spores would germinate, and then be killed on either the second or third days. In practice, such double heat treatments are rarely encountered, and the process is not successful in totally inactivating spores because of the unpredictability of the spore germination process. The same applies to double pasteurisation processes, which have not been found to be effective (Brown *et al*., 1979).

7.6 Pasteurisation

7.6.1 *Introduction and principles*

In terms of historical perspective, two key references still worth consulting are Cronshaw (1947) and Davis (1955). The first holder pasteurisation system was introduced in Germany

in 1895 and in the USA in 1907. Thus by 1895, it was well recognised what was required for an effective pasteurisation process: 'we know that this process (pasteurisation) if properly carried out will destroy all disease germs' and 'a thoroughly satisfactory product can only be secured where a definite quantity of milk is heated for a definite period of time at a definite temperature. Then too, an apparatus to be efficient must be arranged so that the milk will be uniformly heated throughout the whole mass. Only when all particles of milk are actually raised to the proper temperature for the requisite length of time is the pasteurisation process complete.' This sound advice has withstood the test of time and forms the main thrust of current milk heat treatment regulations, reviewed recently by Komorowski (2006).

High-temperature, short-time (HTST) continuous processes were developed between 1920 and 1927, and for some time, the ability of this process to produce safe milk was questioned. In 1927, North and Park established 15 combinations of temperature and time, which inactivated the tuberculosis bacillus (Cronshaw, 1947). These experiments were performed by heating milk heavily infected with bacilli under different conditions and injecting the treated bacilli into guinea pigs. Successful temperature–time combination heat treatments, i.e. those where the animals survived, ranged from 54.4°C (130°F) for 60 min up to 100°C (212°F) for 10 s. Others were 71.1°C (160°F) for 20 s or 60°C (140°F) for 10 min. Further developments were made in the classification of tests for evaluating the pasteurisation process. These included tests for raw milk quality: (a) as visual inspection and detection and removal of faulty milk on arrival at the dairy (i.e. the platform test, Davis, 1955), (b) assessing pasteurisability by the survival of thermodurics (c) measuring the efficiency of pasteurisation by measuring pathogen inactivation and phosphatase activation, first described in 1935 on the basis of the finding that conditions required to inactivate *Mycobacterium tuberculosis* were just slightly less than those required to inactivate alkaline phosphatase, (d) assessing recontamination in terms of thermophilic and coliform bacteria, and the methylene blue test and (e) measuring general bacterial quality, including organisms surviving pasteurisation together with contaminating organisms (plate count). The methylene blue test is now little used, but the detection of alkaline phosphatase activity is still used as a statutory test in many countries.

By this time, the bacteria in pasteurised milk were being identified and the detrimental effects of thermoduric bacteria were being recognised. Factors affecting keeping quality were being investigated as well as conditions that induced a cooked flavour and resulted in the loss of the cream line. The role of phosphatase as an indicator was introduced and there were interesting comparisons between the holder or batch process and the HTST process. Problems with milkstone had also been recognised.

By the early 1950s, HTST processing accounted for about 75% of all milk pasteurised in the UK, and was the favoured process by the larger dairies (Davis, 1955). Energy saving was not an important consideration. Plant capacities were typically 1818 L h^{-1} (400 gal h^{-1}) in 1947, but a few years later had increased to 9092 L h^{-1} (2000 gal h^{-1}), with a range from 2273 to 22 730 L h^{-1} (50–5000 gal h^{-1}). Run times of 4–5 h were the norm; maintaining the cream line was important, and there were excellent descriptions of different equipment set-ups for conducting the more traditional holder process. One then current concern was that some coliform bacteria were surviving HTST pasteurisation (Davis, 1955).

Moving toward the present, pasteurisation has been defined by the International Dairy Federation (IDF, 1986) as a process applied with the aim of avoiding public health hazards arising from pathogenic microorganisms associated with milk, by heat treatment which is consistent with minimal chemical, physical and organoleptic changes in the product. According to Codex Alimentarius (Anonymous, 2003b),

> *Pasteurisation is a heat treatment aimed at reducing the number of any harmful microorganisms in milk and liquid milk products, if present, to a level at which they do not constitute a significant health hazard. In addition, it results in prolonging the keepability of milk or the liquid milk product and in only minimal chemical, physical and organoleptic changes. Pasteurisation conditions are designed to effectively destroy the organisms (*Mycobacterium tuberculosis *and* Coxiella burnetti*). Pasteurisation of milk and cream results in a negative alkaline phosphatase reaction immediately after the treatment. For milk, the minimum pasteurisation conditions are those having bactericidal effects equivalent to heating every particle of the milk to 72°C for 15 s (continuous flow pasteurisation) or 63°C for 30 min (batch pasteurisation). Other equivalent conditions can be obtained by plotting a line joining these points on a log time versus temperature graph*.

Pasteurisation causes little change to the colour, flavour and appearance of the milk, (although devotees of raw milk will contest this), and no significant reduction in nutritional value. It causes minimal whey protein denaturation (5–15%) and does not alter enzymatic coagulation properties during the manufacture of cheeses.

Pasteurised products should last for up to 48 h without refrigeration (at, say, 20°C), and for several days when stored refrigerated. However, longer keeping qualities and between 10 and 16 days at 4°C are now achievable, when produced from high-quality raw milk, under optimum technical and hygienic conditions. Milk can still be pasteurised by the holder or batch process at 63°C for 30 min, but as discussed earlier, the HTST process now predominates, with capacities over 50 000 l h^{-1}, and running times of up to 20 h. Minimal conditions are at 72°C for 15 s, but the actual conditions will vary from country to country. A recent survey of the conditions used in Australian factories revealed a range from 72°C for 15 s to 78–80°C for 25 s (Juffs & Deeth, 2007). The more severe heating conditions are being used as a precautionary measure for the presence of any heat-resistant *Mycobacterium avium* subsp. *paratuberculosis* (MAP). As described elsewhere, the holding tube temperature and time is not the whole story, and the heating and cooling periods provide an extra margin of safety.

The original phosphatase test for assessing the adequacy of pasteurisation was based on the reaction of phosphatase with disodium phenyl phosphate. If phosphatase is present, it will release phenol, which is determined colorimetrically (Davis, 1955). It was claimed to be able to detect the presence of about 0.2% raw milk (addition) in pasteurised milk, as well as under processing, for example 62°C instead of 62.8°C for 30 min or 70°C rather than 72°C for 15 s. Since then, a more automated test based on fluorescence measurement (e.g. Fluorophos) has increased the sensitivity of the method further, being able to detect the presence of 0.006% added raw milk. This is a very useful quality assurance test procedure, and its introduction should further help detect low levels of post-pasteurisation contamination, which should also

reduce the incidence of pathogens in pasteurised milk. Tests for detecting post-pasteurisation contamination are reviewed in IDF (1993).

In some regulations, it is required that pasteurised milk should show a positive lactoperoxidase activity, to prevent the milk being over processed (Statutory Instruments – SI, 1995). In Europe, milks which show a negative lactoperoxidase activity are designated high temperature pasteurised (European Union – EU, 1992). The EU regulations require that freshly pasteurised milk should be deemed to pass a coliform test, and to have a plate count of less than 50 000 mL^{-1} after incubation for 5 days at 6°C, although these are in the process of revision.

The heat resistance of a wide range of other enzymes found in raw milk in the pasteurisation range has also been reviewed by Griffiths (1986) and Andrews *et al*. (1987). Lactoperoxidase activity, determined on a plate heat exchanger (PHE) for 15 s, was generally lower than expected from the laboratory data. Using a PHE, enzyme activity was almost destroyed at 78°C for 15 s, and completely destroyed at 80°C for 5 s. The enzyme appeared sensitive to temperatures above 75°C, with a *z*-value of 5.4°C. Griffiths (1986) determined the heat resistance of several other indigenous milk enzymes; these have also been summarised by Lewis & Heppell (2000).

Enzymes in raw milk may cause some other problems in pasteurised milk. For example, indigenous lipases may give rise to soapy off-flavours, especially if raw milk is subjected to excessive agitation at temperatures up to 40°C, e.g. during pumping or when mixing flavoured milk or other similar products. However, it is unlikely that bacterial lipases and proteases, which are very heat resistant, will cause problems in pasteurised milks because of their relatively short shelf life and refrigerated storage conditions.

7.6.2 *Methods of pasteurisation*

Holder or batch heating

Cronshaw (1947) and Davis (1955) both provide excellent descriptions of equipment for the holder or batch process – individual vessels (heated internally) and externally heated systems with one or more holding tanks. The batch heating time and factors affecting it can be predicted from equations given in Section 7.13. It is still being used in many countries in some small-scale pasteurisation processes. In answer to the question – Does HTST pasteurisation result in as good a bottle of milk as does the holder process, Yale in 1933 concluded that one method of pasteurisation produces as good a bottle of pasteurised milk as does the other when sound methods are used and when conditions are comparable. The authors have not seen anything of late to contradict this.

Continuous heating

The main types of indirect heat exchanger for milk are the PHE and the tubular heat exchanger (THE). PHEs are widely used for pasteurisation processes; they have a high overall heat transfer coefficient (OHTC), and are generally more compact than THEs. Their main limitation is pressure, with an upper limit of about 2 MPa (20 bar). The normal gap width between the plates is between 2.5 and 5 mm, but wider gaps are available for viscous

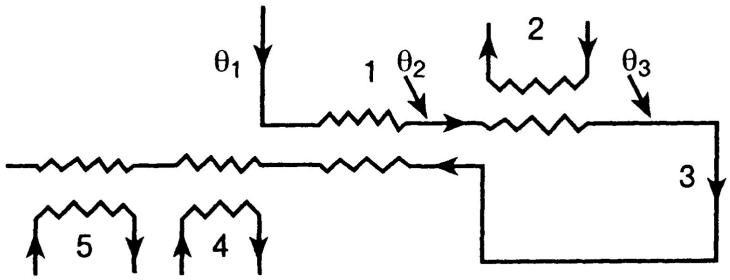

Fig. 7.1 Heat exchange sections for HTST pasteuriser. Note: 1, regeneration; 2, hot water section; 3, holding tube; 4, mains water cooling section; 5, chilled water cooling section. Reprinted from *Modern Dairy Technology*, Volume 1, 1994, R.K. Robinson, with kind permission of Springer Science and Business Media.

liquids to prevent large pressure drops. In general, PHEs are the cheapest option, and the one most widely used for low-viscosity fluids. Maintenance costs may be higher, as gaskets may need replacing, and the integrity of the plates also needs evaluating regularly. This is especially so for plates in the regeneration section, where a cracked or leaking plate may allow raw milk to contaminate already pasteurised milk. They are also more prone to fouling-related problems.

THEs have a lower OHTC than plates, and generally occupy a larger space. They have slower heating and cooling rates with a longer transit time through the heat exchanger. In general, they have fewer seals, and provide a smoother flow passage for the fluid. A variety of tube designs are available to suit different product characteristics. Most tubular plants use a multi-tube design. They can withstand higher pressures than PHEs. Although they are still susceptible to fouling, high pumping pressures can be used to overcome the flow restrictions. THEs give longer processing times than PHEs with viscous materials and with products, which are more susceptible to fouling.

The viscosity of the product is one major factor, which affects the choice of the most appropriate heat exchanger and the selection of pumps. Viscosity will influence the pressure drop causing a problem in the cooling section and when phase transition may take place, for example if coagulation or crystallisation takes place. For more viscous or particulate products, e.g. starch-based desserts or yoghurt with fruit pieces, a scraped surface heat exchanger may be required.

One of the main advantages of continuous systems over batch systems is that energy can be recovered in terms of regeneration. The layout for a typical regeneration section is shown in Figure 7.1. The hot fluid can be used to heat the incoming fluid, thereby saving on heating and cooling costs. Regeneration efficiencies over 90% can be obtained (see equation for regeneration efficiency in Section 7.13). Although high-regeneration results in considerable savings in energy, it necessitates the use of higher surface areas, resulting from the lower-temperature driving force, and a slightly higher capital cost for the heat exchanger. This also means that the heating and cooling rates are also slower, and the transit times longer, which may affect the quality.

For milk and cream, homogenisation must be incorporated to prevent fat separation. As homogenisation of raw milk is a very effective way of initiating lipolysis (Deeth & Fitz-Gerald, 2006), it must be carried out immediately before or after pasteurisation, which

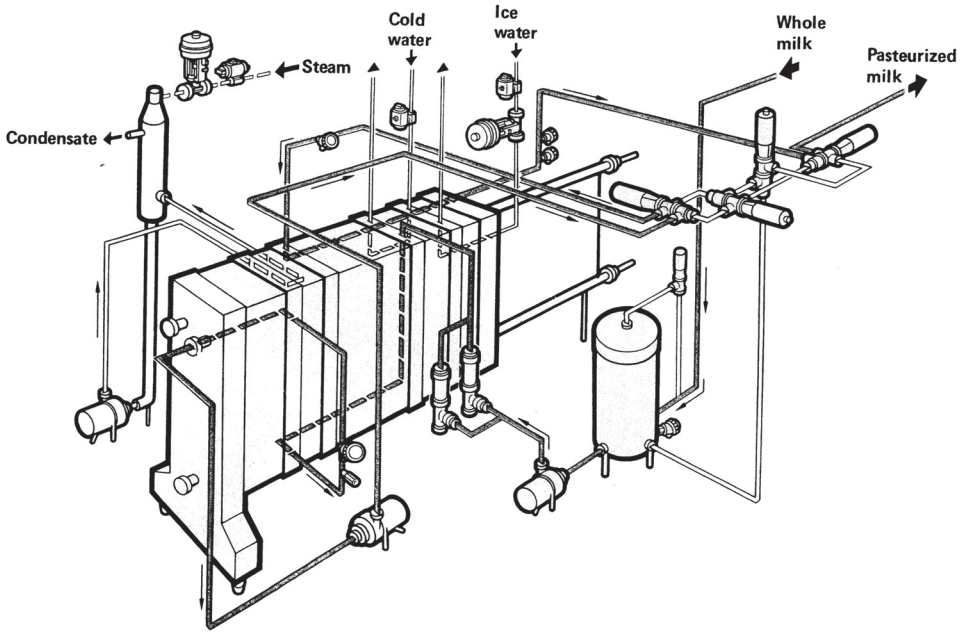

Fig. 7.2 The layout of a typical HTST pasteuriser. With permission of Tetra Pak, Lund, Sweden.

inactivates the native lipase. Homogenisation before pasteurisation is preferable as homogenisers can introduce post-pasteurisation contamination if used after pasteurisation. While pre-pasteurisation homogenisation is simple in a continuous flow system, it is more difficult to link with batch pasteurisation as the time delay between homogenisation, and when the milk reaches pasteurisation temperature, can result in an unacceptable amount of lipolysis. However, this problem can be largely overcome by homogenising the milk at $\geq 50^{\circ}$C (Deeth, 2002).

The layout of a typical HTST pasteuriser and its accessory services is shown in Figure 7.2. The holding time is controlled either by using a positive displacement pump or by a centrifugal pump linked to a flow controller, and the temperature is usually controlled and recorded. Note that a booster pump can be incorporated to ensure that the pasteurised milk is at a higher pressure than the raw milk in the regeneration section, i.e. to eliminate post-processing contamination in this section. A flow diversion valve diverts underprocessed fluid back to the feed tank. In continuous processing operations, there will be a distribution of residence times, and it is vital to ensure that the minimum residence time (i.e. the time for the fastest element of the fluid to pass through the holding tube) is greater than the stipulated time, to avoid underprocessing. In a fully developed turbulent flow, the minimum residence time is about $0.83t_{av}$, whereas in streamline flow, it is $0.5t_{av}$, where t_{av} is the average transit time through the holding tube (see Section 7.13).

Most HTST pasteurisers are of the plate type, and these should be tested for leaks periodically. Consideration should be given to ensuring that if leaks do occur, they do so in a safe fashion; i.e. pasteurised milk is not contaminated with cooling water or raw milk

in the regeneration section. The control instrumentation, diversion valves and other valves should be checked regularly.

7.6.3 *Factors affecting the quality of pasteurised milk*

The main control points for ensuring good quality pasteurised milk products are

- raw milk quality,
- processing conditions: temperature and holding time,
- post-processing contamination (PPC) and
- storage temperature.

Raw material quality

Raw milk may contain pathogenic microorganisms from the farm environment, including vegetative bacteria, such as *Staphylococcus aureus*, *Campylobacter jejuni*, *Salmonella* spp., *Escherichia coli*, *Yerisinia enterocolitica*, and spore formers, such as *Bacillus* and *Clostridium* species. These major vegetative pathogens can be effectively controlled by pasteurisation, and are not the main determinants of keeping quality. The main interest is in what survives pasteurisation or mild heat treatments. Thermoduric bacteria are defined as those which survive pasteurisation conditions, e.g. 63°C for 30 min or 72°C for 15 s, whereas spores produced by spore-forming bacteria survive 80°C for 10 min. *Bacillus cereus* spores are relevant here, being the main pathogen which will survive pasteurisation and grow at low temperature. *Bacillus* can cause defects in heat-treated milk, for example bitty cream, and produce an intense bitter flavour, but it rarely causes food poisoning because infected products are so unacceptable.

Processing times and temperatures

Normal HTST conditions for milk are 72°C for 15 s. One interesting question relates to the use of higher temperatures (up to 90°C) for pasteurisation. In general, milk treated at such a temperature has a reduced keeping quality compared to milk heated at 72°C for 15 s. This was first recognised by Kessler & Horak (1984), and then by Schroder & Bland (1984), Schmidt *et al*. (1989), Gomez Barroso (1997) and Barrett *et al.* (1999). It is a question that should be often revisited, since it would be logical to expect a more severe heating process to result in improved keeping quality. Another drawback is that a cooked flavour will start to be noticeable between 85 and 90°C. Thus, those using or considering using more stringent pasteurisation conditions than the minimum conditions should be aware of these disadvantages. The usual explanation for this unexpected phenomenon is that the more severe conditions cause heat shocking of the *Bacillus* spp. spores which can then germinate, grow and reduce the keeping quality of the milk. However, recent evidence suggests that the lactoperoxidase system (LPS) also plays a role. The LPS involves the enzyme lactoperoxidase, hydrogen peroxide and thiocyanate, all of which are present in raw milk. The oxidation products, e.g. hypothiocyanite, exhibit strong anti-microbial activity by oxidising sulphydryl groups of bacterial cell walls (Reiter & Harnulv, 1982). The LPS can

be further activated in raw milk by small additions of thiocyanate and hydrogen peroxide, and can be used to keep raw milk longer in countries where refrigeration is not widespread (IDF, 1988). Lactoperoxidase inactivation is very temperature-sensitive, and as described earlier, some heat treatment regulations now require that pasteurised milk should show a positive lactoperoxidase activity. Marks *et al*. (2001) showed that pasteurisation conditions of 72°C for 15 s, resulting in an active LPS, greatly increased the keeping quality of milks inoculated with *Pseudomonas aeruginosa*, *S. aureus* and *Streptococcus thermophilus*, when compared to heating at 80°C for 15 s. However, pasteurisation had no effect on the keeping quality of milks challenged with *B. cereus* spores. It may be possible to exploit some other natural anti-microbial systems in raw milk. These have been described in more detail by the IDF (1994). Double pasteurisation processes have been found not to be effective (Brown *et al*., 1979) and, as such, are rarely used.

Problems arising from a build-up of thermophilic bacteria in the heating and cooling sections associated with long operating times in continuous heat exchangers have been recognised for some considerable time (Cronshaw, 1947). Bacterial numbers in pasteurised milk have been found to increase slowly over the initial 8–9 h, and then more rapidly over the remaining period of operation. The main growth occurs in the regenerative section. *Bacillus licheniformis* and *S. thermophilus* have been implicated (Lehmann *et al*., 1992; Lehmann, 1996).

There has been much interest recently in *M. avium* subsp. *paratuberculosis* (MAP), and whether it would survive pasteurisation. MAP levels found in raw milk appear to be low, but there is no real indication of true levels because of the decontamination procedures used to remove the other bacteria in raw milk and its extremely slow growth rate. MAP levels found in milks subjected to pasteurisation are also low. There are many inconsistencies in the experimental results. These are discussed in several publications (Hammer *et al*., 1998; Grant *et al*., 2001; IDF, 2004; Grant, 2006).

Results from surveys on raw milks and pasteurised milks are also inconclusive in that MAP was found in 2% of both raw and pasteurised milk samples tested. This again suggests that pasteurisation has no significant effect. Clearly, the heat resistance data generated to date for MAP are inconclusive and do not permit an accurate assessment of the efficacy of the pasteurisation process with regard to MAP. Collated information has been published by the IDF (1998, 2004). In the UK, it has been recommended that HTST pasteurisation conditions should be increased to 72°C for 25 s as part of a strategy for controlling MAP in cows' milk.

One parameter which has been used for some considerable time to compare pasteurisation processes is the pasteurisation unit (PU). One PU results from a heat treatment at 60°C for 1 min, and the equivalent z-value is high (10°C); thus, the number of PUs is given by:

$$PU = 10^{\frac{T-60}{10}} t,$$

where t = time (min)

Thus, a treatment at 63°C for 30 min would have a value of ~60, whereas HTST conditions would give a value of about 4. Clearly, there is an inconsistency here, no doubt derived from the high z-value chosen for this calculation.

Kessler (1989) introduced a different parameter (p*) for characterising and comparing pasteurisation processes, especially at temperatures higher than 72°C. According to him, 72°C for 15 s corresponds to a $p* = 1$. It is noteworthy that 63°C for 30 min corresponds to a p* of approximately 9, suggesting from this approach that such milk would be considerably overprocessed. Since this is known not to be the case, it demonstrates that practical experience should always dictate what conditions to use.

However, pasteurisation conditions do vary from one country to another. In the USA, a wide range of conditions are used including 63°C for 30 min, 77°C for 15 s, 90°C for 0.5 s and 100°C for 0.01 s (Busse, 1981)

Other products pasteurised are creams and ice cream mix. In the UK, minimum temperature–time conditions are 72°C for 15 s and 79°C for 15 s, respectively, although conditions for these products are more severe in other countries. Codex Alimentarius (Anonymous, 2003b) states that the fat content of cream makes it is necessary to apply minimum pasteurisation condition of 75°C for 15 s.

Post-pasteurisation contamination

Post-pasteurisation contamination (PPC) was recognized as a problem in the 1930s, and is now considered to be a very important determinant of keeping quality. Muir (1996a,b) describes how this was recognised both for milk and for cream in the early 1980s. PPC encompasses the recontamination of the product anywhere downstream of the end of the holding tube. It can occur in the regeneration or cooling sections, in storage tanks and in the final packaging of the product, due to poor hygienic practices. It can greatly be reduced by ensuring that all internal plant surfaces in contact with the product are heated at 95°C for 30 min. It can only be completely eliminated by employing aseptic techniques downstream of the holding tube. One of the main safety concerns is recontamination of the product with pathogens from raw milk, and this could occur due to bypassing of the holding tube by a number of possible routes, including pinhole leaks in plates and through pipelines that have been set up for cleaning and disinfecting. In terms of reducing keeping quality, recontamination with Gram-negative psychrotrophic bacteria is very important.

The presence in a pasteurised product with a high count of microorganisms (e.g. coliform bacteria), which should have been inactivated by pasteurisation, is indicative of PPC. IDF (1993) catalogued a large number of tests, which can be used to determine the extent of the problem. In practical situations where the keeping quality of milk starts to deteriorate or is below expectations, the most likely explanation is an increase in PPC and this should be the first factor to be investigated.

Storage temperature and time

In general, the lower the storage temperature, the better will be the keeping quality, bearing in mind the costs and practical problems of ensuring low temperatures throughout the cold chain and in domestic refrigerators. Before domestic refrigeration was commonplace, Cronshaw (1947) reported that the shelf life of pasteurised milk was about 24 h. Household refrigeration helped to improve this considerably, and in the UK by 1957, 10% of households

had a refrigerator, increasing to 30% by 1962 and up to 90% by 1979. Raw milk is stored at typically 4°C; temperatures in the cold chain are slightly higher, and are likely to be higher still in domestic refrigerators. Many of our results have confirmed that pasteurised milk produced from good quality raw milk could be stored for up to 18 days at 8°C and between 25 and 40 days at 4°C (Ravanis & Lewis, 1995; Gomez Barroso, 1997). However, it must be emphasised that these experiments were performed with good quality raw milk, i.e. the counts immediately after pasteurisation were never above 10^3 colony-forming units (cfu) mL^{-1}, even for raw milk stored for up to 8 days at 4°C prior to pasteurisation. Also, care was taken to minimise PPC. These results also illustrate that good keeping quality can be achieved by eliminating PPC, and can be further enhanced by using low storage temperatures.

From our experience, there are some other interesting questions relating to pasteurised milk. For example, why does pasteurised skimmed milk have a shorter shelf life than pasteurised whole milk? This observation has been reported by several authors (Janzen *et al.*, 1982; Brown *et al.*, 1984; Deeth *et al.*, 2002). The latter authors reported that the rates of growth of psychrotrophic bacteria were not significantly different in the two milks and the bacterial types, all pseudomonads, present at spoilage were also similar. The different spoilage behaviours were attributed to greater proteolysis in skimmed milk than in whole milk, caused by higher production of protease and greater susceptibility of the protein to protease attack. Lipolysis in the whole milk also contributed to the spoilage flavours of the product, but not skimmed milk. Some other interesting questions relate to differences in the keeping qualities of pasteurised cow's and goat's milk and whether organic milk has a better keeping quality than non-organic milk. To answer these questions in a scientific manner is not straightforward, as one would likely find significant variations between different cow's and goat's milks, and between different organic milks for reasons outlined earlier in the chapter.

7.7 Sterilisation – safety and spoilage considerations

Sterilisation of milk to enable it to be kept at room temperature for several months became a commercial proposition in 1894. Milk can either be sterilised in bottles or other sealed containers, or by continuous UHT processing followed by aseptic packaging (see below). Very good accounts of the procedures for producing in-container sterilised milk and problems associated with it have been provided by Cronshaw (1947) and Davis (1955).

From a safety standpoint, the primary objective is the production of commercially sterile products with an extended shelf life. The main concern is inactivation of the most heat-resistant pathogenic spore, namely *Clostridium botulinum*. Since milk is a low-acid food (pH > 4.5), the main criterion is to achieve 12 decimal reductions of *Cl. botulinum*. This occurs when a product is heated at 121°C for 3 min, at its slowest heating point (Anonymous, 1991). The microbial severity of an in-container sterilisation process is traditionally expressed in terms of its Fo value. This takes into account the contributions of the heating, holding and cooling periods to the total lethality and is expressed in terms of minutes at 121°C. It provides a useful means of comparing processes. The minimum Fo value for any low-acid food should be 3.

Cl. botulinum is rarely found in raw milk. More common sporeformers are *Bacillus* species of which some, such as *B. stearothermophilus* (now known as *Geobacillus stearothermophilus*) and *B. sporothermodurans* (Hammer *et al*., 1996), form highly heat-resistant spores, which are not destroyed by a process with an Fo of 3. These bacteria may cause spoilage, but they are not pathogenic. Thus, a minimum 'botulinum cook' will produce a product which is safe, but not necessarily sterile. For foods which may contain highly heat-resistant spores, a heat treatment achieving two or more decimal reductions is recommended, corresponding to an Fo value of 8. Target contamination rates should be less than 1 in every 10 000 containers.

Spore counts in raw milk have been rarely reported to exceed 10^3 cfu mL^{-1}, although Bramley & McKinnon (1990) reported that they may reach 5000 cfu mL^{-1}. Spores are mainly derived from surfaces of teats in contact with bedding materials. The most common *Bacillus* spores isolated from teat surfaces are *B. licheniformis*, *B. subtilis* and *B. pumilis* with lower numbers of *B. cereus*, *B. firmus* and *B. circulans.* Most common in raw milk are *B. licheniformis*, *G. stearothermophilus* and *B. cereus.* Very heat-resistant spores, such as *G. stearothermophilus*, are usually only a small proportion of the total.

7.8 In-container sterilisation

Foods have been sterilised in sealed containers, such as cans, for over 200 years. Milk was originally sterilised in glass bottles sealed with a crown cork, but more recently, plastic bottles have been used. Milk sterilisation really developed after 1930 with the advent of the crown cork, which helped with the mechanisation of the bottle-filling process, and the reuse of bottles. In general, the basic principles have remained the same.

The main aim is to inactivate heat-resistant spores, thereby producing a product which is 'commercially sterile', with an extended shelf life. Practical drawbacks of in-container sterilisation processes are that the product heats and cools relatively slowly, and that temperatures are limited by the internal pressure generated. However, many dairy products are still produced this way worldwide, including sterilised milk, evaporated milk and canned desserts such as custard and rice pudding.

Sterilised milk is still produced in many countries, and in essence, the manufacturing procedure is not too far removed from that used over 50 years ago. Milk is clarified using a centrifuge, e.g. a Bactofuge™, with claimed spore removal of greater than 99% (2 $\log_{10}$ reductions). It is heated using similar equipment to that used for pasteurisation. It is then homogenised at 63–82°C, for example at a single-stage pressure of about 20 MPa or double stage at about 17 and 3.5 MPa. It is then filled into glass bottles between 74 and 80°C under conditions which give minimal frothing, and sealed using a crown cork. Plastic bottles are sealed at a lower temperature of 54–55°C. Care should be taken to avoid conditions in balance tanks, which may be conducive to growth of thermophiles. Ashton & Romney (1981) cite sterilisation processing conditions of 110–116°C for 20–30 min, depending on the extent of cooked flavour and colour preferred by the consumer. Batch or continuous retorting processes may be used (Davis, 1955). Other processing details are outlined by Ashton & Romney (1981); these include more detail on continuous retorts, such as hydrostatic or rotary valve sealed sterilisers, which are capable of higher temperatures and shorter times

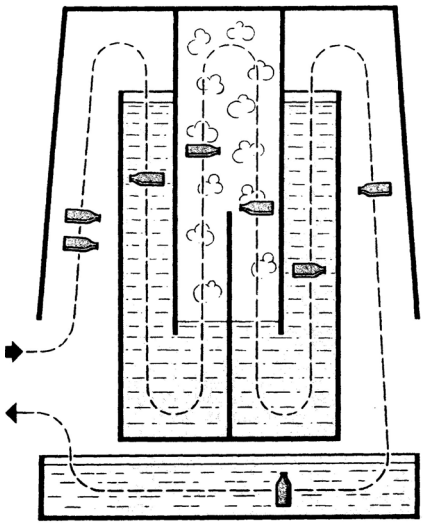

Fig. 7.3 A continuous retort for sterilisation of glass or plastic bottles. With permission of Tetra Pak, Lund, Sweden.

(132–140°C for 12 min), and the use of steam for glass bottles or steam/air mixtures for plastic bottles (see Figure 7.3).

Davis (1955) recognised the need for ensuring that raw milk to be used for sterilisation was not heavily contaminated with bacterial spores. Today, this remains an important control variable. Sweet curdling was the chief bacterial fault, due to highly resistant spores of *B. subtilis* and *B. cereus*. Bacterial growth was found to produce other taints, such as carbolic, bad (e.g. oxidised) or cardboard taints. Ashton & Romney (1981) reported that the failure level of well-produced sterilised milks is of the order of 1 in 1000 units, although it may be as high as 5–10% in situations where there are large numbers of thermotolerant spores in the raw material or other contamination arising in the process.

A recognised test for ensuring adequate sterilisation is the turbidity test, developed by Aschaffenburg in 1950. This test measures whey protein denaturation and it is an indirect test (similar to phosphatase), as complete denaturation would indicate that the milk was adequately sterilised. Milk (20 mL) is mixed with ammonium sulphate (4 g), which causes casein and any associated denatured whey protein to precipitate. The mixture is filtered, producing a clear filtrate, which contains any undenatured whey protein present in the milk sample. The filtrate is then boiled, which causes any undenatured whey protein to be denatured, thereby producing a turbid solution, the amount of turbidity being proportional to the amount of undenatured whey protein in the milk. Some regulations state that sterilised milk should produce a negative turbidity result; i.e. it should be heated for such a time as to fully denature the whey proteins. In principle, UHT heating of milk should result in some undenatured whey protein, but UHT processes with extensive heating and cooling profiles are more severe and will also give a negative turbidity result. Thus, the turbidity test will not always distinguish UHT milk from sterilised milk. In fact, many UHT milk samples show a negative turbidity. Methods for distinguishing between sterilised and UHT milk have been discussed

in detail by Burton (1988). However, this is made difficult by the wide range of times and temperatures which are permitted. This includes a combined process, which involves the production of milk under UHT conditions, e.g. 137°C for 4 s, and is filled into bottles which are then sealed and passed through a conventional retorting process. Although the retorting is much reduced, it is generally just sufficient to ensure a negative turbidity result. In terms of determining the sterilisation effect, if this is to be treated as a single process, the critical point is to ensure that the milk does not become recontaminated in the intermediate filling process, especially with bacterial spores. This process was found to reduce the incidence of spoilage due to spore survivors (Ashton & Romney, 1981). There is also plenty of opportunity for spore inactivation due to high temperatures being maintained for some considerable time.

Sterilised milk has a rich creamy appearance, perhaps helped by Maillard browning components, a distinct cooked flavour (rich, nutty, caramelised), which once acquired, makes other heat-treated products taste insipid. It is considerably browner than raw milk, the extent of browning depending on the severity of the heat treatment. Thus, Maillard browning contributes to product quality in terms of its colour and flavour, although not everybody will find sterilised milk to be as palatable as pasteurised milk.

Sterilisation causes more loss of nutrients than any other heat treatment. For example, losses of the water-soluble vitamins B1 and B12 have been reported to be 30–40% and 80–100%, respectively (Schaafsma, 1989). Furthermore, it cannot be coagulated with rennet, unless calcium chloride is added (Kessler, 1981, 1989).

To summarise, sterilised milk is still produced in quantity in some countries, with much of it now produced in retortable disposable plastic bottles with a metal foil cap, rather than in returnable glass bottles.

7.9 UHT processing

7.9.1 *Introduction and principles*

UHT processing of milk combined with aseptic packaging was introduced to produce a shelf-stable product with minimal chemical damage compared with in-container sterilised milk. UHT milk may have a shelf life of up to 12 months, although in practice, it is usually consumed much earlier than this. In countries where it is a minor segment of the milk market, it is often used as a convenience product, and used when pasteurised milk is not available; whilst in countries where it is the major type of milk available, it is used regularly. In the former situation, UHT milk may need to be stable over a long period of time, while in the latter case, the desired shelf life may be $\leq$3 months.

UHT treatment is normally in the range 135–150°C in combination with appropriate holding times necessary to achieve 'commercial sterility'; i.e. microorganisms are unlikely to grow in the product under the normal conditions of storage (Burton, 1988; Lewis & Heppell 2000; Anonymous, 2003b). In practice, the products are checked for sterility by incubating at 55°C for 7 days or at 30°C for 15 days, and testing for bacterial growth (Anonymous, 2003b).

Some useful bacteriological and chemical indices have been developed to describe the effects of a particular heating regime on the bacteria and chemical components of milk,

respectively. The major ones are *B** and Fo (bacterial) and *C** (chemical). *B** is a measure of the bacteriological effect of a heat treatment relevant to treatment at a reference temperature of 135°C. A process with $B^* = 1$ produces a nine-decimal reduction of thermophilic spores assuming a z value of 10.5°C, and is equivalent to holding the product at 135°C for 10.1 s; this is the recommended minimal value of *B** for a UHT process. This differs from the other bacterial index Fo, which is commonly used for in-container sterilisation, where the reference temperature is 121.1°C (250°F) (see Section 7.7). While it is a good measure of the lethality of the heat treatment, it is more appropriate to heating at temperatures around 120°C than around 140°C. As indicated above, sterilisation processes should have an Fo $\geq$ 3 to ensure bacteriological safety. Although a direct correlation is not strictly correct, an Fo of 3 corresponds roughly to a *B** of about 0.85.

*C** is a chemical index of heat treatment relevant to a reference temperature of 135°C based on the kinetics of destruction of the vitamin thiamine; a $C^* = 1$, which equates to a 3% loss of thiamine, is considered to be the desired upper limit for a UHT process to avoid excess damage. While thiamine is seldom measured in milk, the kinetics of its destruction by heat are deemed to provide a reasonable indication of the chemical effect of heat, and allow the effect of different heating conditions to be compared. However, other chemical components change with temperature and time differently. For example, heating at 90°C for 30 s, common UHT preheating conditions, destroys less than 0.1% of thiamine, but denatures up to 75% of the major whey protein, i.e. β-lactoglobulin.

There are two basic principles of UHT processing, which distinguish it from in-container sterilisation. First, for the same bactericidal effect, a high-temperature-short-time treatment (as in UHT) results in less chemical change than a low-temperature – long-time treatment (as in in-container sterilisation). This is because the Q_{10}, the relative change in reaction rate with a 10°C change in temperature, is much lower for chemical change (typically ~3) than for bacterial kill (typically ~10 for spore destruction), or alternatively, the z values for chemical reactions are higher (see Section 7.3). Based on the Q_{10} values of 3 and 10, the chemical change at 145°C is only about 2.7% of that at 115°C, for the same bactericidal effect.

The second principle is that the need to inactivate thermophilic bacterial spores dictates the minimum times and temperatures which can be used, while the need to minimise undesirable chemical alterations, such as undesirable flavour and colour changes, and vitamin destruction dictate the maximum times and temperatures. In terms of the indices discussed above, the recommended minimum conditions are those with a *B** of 1, and the maximum conditions with a *C** of 1.

It is worth noting that a *B** of 1 refers to 9 $\log_{10}$ reduction of thermophilic spores, which represents a more intense heat treatment than 9 $\log_{10}$ reduction of mesophilic spores. However, since the discovery of the extremely heat-resistant mesophilic sporeformer, *B. sporothermodurans* in UHT milk (IDF, 2000), a higher level heat treatment has been recommended.

In order to inactivate highly heat-resistant spores, higher temperatures ($\geq$150°C) for very short times (<1 s) have been proposed. The use of such extreme treatments is generally limited by the UHT plant's physical configuration. However, an innovative steam injection (ISI) process has been developed in the Netherlands to heat milk at 150–200°C for less than 0.1 s. It was shown to destroy heat-resistant spores (Huijs *et al.*, 2004).

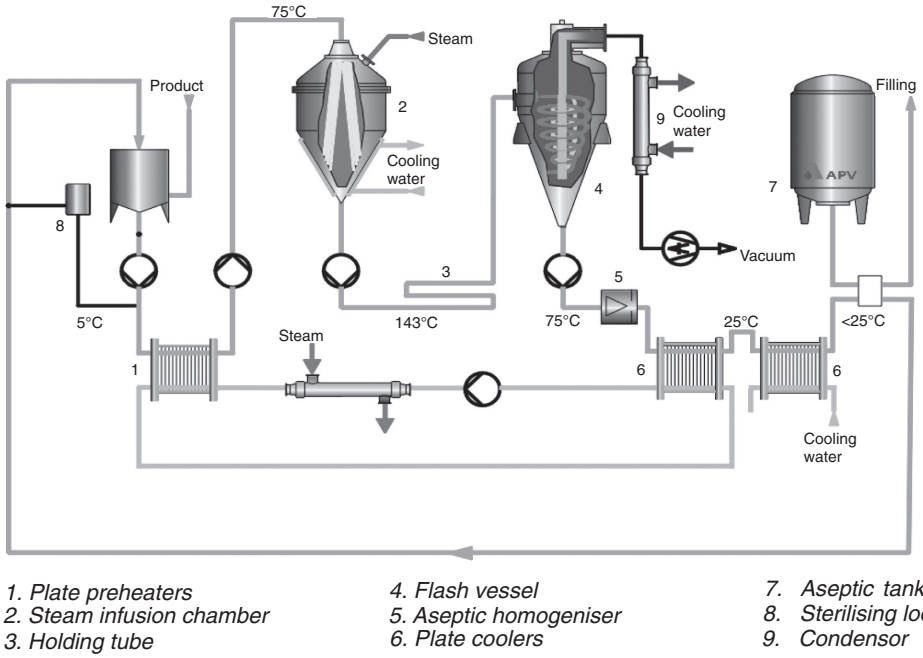

Fig. 7.4 The layout of a direct (infusion) UHT plant. With permission of APV Company.

7.9.2 *Methods of UHT processing*

Background

UHT heating can be either 'direct' or 'indirect'. In direct heating, superheated steam is mixed with milk while, in indirect heating, a heat exchanger transfers heat across a partition between the milk and the heating medium, either steam or hot water (Mehta, 1980; Burton, 1988). In THEs, the partition is the wall of the stainless steel tube, and in PHEs, it is the stainless steel plate.

The UHT process involves the following stages: preheating with heat regeneration, holding at preheat temperature, heating to sterilisation temperature, holding at sterilisation temperature, cooling and aseptic packaging (see Figure 7.4). In addition, a homogenisation step is usually included either before or after the high-heat holding section. In commercial processing of UHT milk, preheating (to ∼80–95°C) is usually achieved by using the hot processed milk to heat the incoming cold raw milk. This enables much of the heat used in the process to be regenerated and the cooling water requirement to be reduced (Lewis & Heppell, 2000). The preheated milk is often held for a short time (15 s to a few min) to denature the whey proteins, principally β-lactoglobulin, to reduce their ability to foul, or deposit on, the hot surfaces of the high-temperature heating section (Burton, 1988). This processing approach, which is known as a 'protein stabilisation' step, is not usually employed in direct plants because they are much less likely to foul in the high-heat section than the indirect plants due to the reduced access of the milk to high-temperature surfaces.

The preheating and final cooling steps are always performed in indirect heat exchangers; however, the heating to sterilisation temperature after preheating can be either direct or indirect. This is the stage that characterises a plant as either 'direct' or 'indirect'. The cooling section immediately after the high-heat section also differs in the two systems: (a) direct plants use expansion cooling in a vacuum chamber and (b) indirect plants use THEs or PHEs (Burton, 1988).

All UHT processes involve aseptic packaging of the product into cartons, plastic bottles or laminated plastic cartons (Robertson, 2006). This is an essential part of UHT processing as it ensures that the sterile product is not contaminated during packaging, thus enabling the product to be stored at room temperature for several months without spoilage by bacterial growth.

Direct heating

There are two major types of direct heating UHT systems known as *steam injection* (steam into milk) and *steam infusion* (milk into steam) (see Figure 7.4). In the former, superheated steam is 'injected' into a stream of milk, while in the latter, milk is sprayed into or allowed to fall as a thin film or fine streams, through a chamber of superheated steam. A major feature of these two systems is the almost instantaneous rise in the temperature of the milk from preheat to sterilisation temperature through the transfer of the latent heat of vaporisation of the steam to the milk. During this heating stage, steam is condensed, and the milk is diluted with water. The degree of dilution depends on the temperature rise of the milk, but for an increase in temperature of 60°C (e.g. from 80°C to 140°C), it is approximately 11% (Lewis & Heppell, 2000). After the milk passes through the high-heat-holding tube, the entrained water is removed in the vacuum chamber, which also rapidly cools the milk to approximately the same temperature as that of the preheated milk. To ensure neither dilution nor concentration of the milk occurs, the total solids of the incoming milk and the processed milk are monitored, and the temperature in the vacuum chamber adjusted if necessary.

The steam used in direct UHT plants must be of high-quality, culinary grade. Poor-quality steam can lead to carry over of off-flavours into the milk (Burton, 1988).

Indirect heating

In indirect heating using PTEs or THEs, the heating medium is either steam or superheated water. When water is used, it flows in the reverse direction to that of the milk. The reverse flow minimises the temperature differential between the two liquids and, in turn, minimises the amount of burn-on. Hot water is a significantly better heating medium than steam with respect to burn-on and flavour of the product as it enables a smaller temperature differential between the milk and the heating medium (Dentener, 1984).

Heating from the preheat temperature to sterilisation temperatures and initial cooling of the sterilised milk is much slower in indirect systems than in direct systems. For example, Biziak *et al.* (1985) reported less than 1 s for each heat transfer operation in direct heating compared with greater than 10 s with indirect methods. In practice, the heating times from preheat to final UHT temperature can be up to 100 s (Tran *et al.*, 2008). Therefore, for a given temperature increase, indirect processes are more severe than direct processes. In

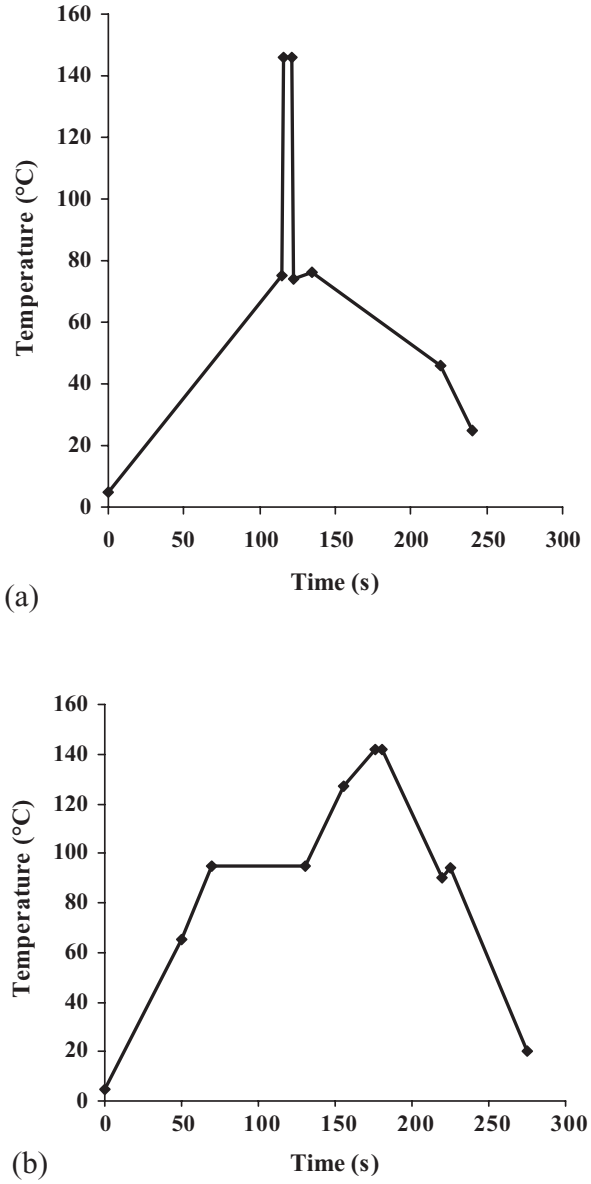

Fig. 7.5 Temperature–time profiles of (a) a direct and (b) an indirect UHT plant.

other words, milk produced in an indirect plant is subjected to a greater heat load than milk processed in a direct plant, with equivalent bactericidal effectiveness. A comparison of direct and indirect temperature–time profiles of two commercial UHT plants is shown in Figure 7.5.

The different heating processes and temperature–time profiles of direct and indirect systems give rise to several differences in the processing characteristics and parameters.

Some key differences are listed in Table 7.1. Of particular note is the higher propensity of indirect plants to foul because of the large area of hot surfaces. In the first stages of the plant where the temperature reached is $<100^{\circ}C$, the main reaction is denaturation of whey proteins, mainly β-lactoglobulin, with subsequent deposition of the denatured protein. In the higher-temperature ($>100^{\circ}C$) sections of the plant, the major reaction is deposition of calcium phosphate, which has reduced solubility at high temperatures. Consequently, the deposit in the high-temperature sections is predominantly mineral, while the deposit in the lower-temperature section is predominantly protein. The build-up of fouling deposit causes a reduction in heat transfer and an increase in pressure. In commercial plants, the product temperature is maintained by increasing the temperature of the heating medium. This exacerbates the fouling because of the increased temperature differential between the heating medium and the product, and eventually, the plant has to be shut down for cleaning (Ansari *et al*., 2006).

The degree of heat energy recovery is another difference between the two systems. In direct heating systems, less regeneration of heat is possible since the steam flashed-off in the vacuum chamber is condensed, and the useful heat is lost from the system. In indirect systems, all the heat in the hot sterile product at the sterilisation temperature (135–150°C) can be used in the regeneration section. Thus, heat regeneration in indirect systems is usually >90%, while it is only about 50% in direct systems (Lewis & Heppell, 2000).

Aseptic packaging

Following sterilisation and subsequent cooling, the sterile product is filled into a sterile container in an aseptic environment and hermetically sealed to ensure sterility is maintained throughout the handling and distribution processes. Two main aseptic packaging systems are used commercially. First, the type that uses pre-formed containers, and second, the type that forms, fill and seals the containers in the aseptic packaging system (von Bockelmann & von Bockelmann, 1998). For both systems, the containers can be either plastic or paperboard. In the first system, plastic bottles are pre-blown while in the second they are blown online. For paperboard cartons, in the first system, pre-cut and folded individual packages are assembled online, while for the second system, the cartons are formed, filled and sealed from a continuous roll of paperboard.

Whatever system is employed, the packaging material or container must be sterilised before being filled with the sterile product. The major sterilisation technique used is a combination of hydrogen peroxide and heat, which is a very effective sterilant for the surface of packaging material. A typical procedure is to treat the packaging material with 35% H_2O_2 at 70°C for 6 s followed by hot air treatment at 125°C to evaporate the residual H_2O_2. An alternative to H_2O_2 alone is a mixture of peracetic acid and H_2O_2 (4%) (Carlson, 1998). Gamma radiation is used to sterilise heat-sensitive packaging materials, such as plastics and laminates; an example is the flexible bags used in Intasept™ aseptic packaging machines.

It is important that a sterile environment is maintained during aseptic packaging to ensure the product remains sterile during transfer from the processing line to the sterile container. Following sterilisation of the filling machine with gaseous hydrogen peroxide, the air entering the filling machine is sterilised and filtered, and maintained at a positive

Table 7.1 Summary comparison of direct and indirect UHT heating systems.

Parameter	Direct systems	Indirect systems
Processing characteristics and parameters		
Preheat hold (at ∼90°C) 'protein stabilisation' step	Uncommon	Common
Sterilising temperature for equal sterilisation effect	3–4°C higher than in indirect systems	
Homogeniser placement	Generally downstream of high-heat section (requires aseptic homogeniser)	Upstream or downstream of high-heat section
Heating rate from preheat to high heat	Fast (<0.5 s)	Slow (∼30–120 s)
Ability to process viscous product	Reasonable, especially with infusion	Little with plate but good capability with tubular heat exchangers
Fouling/burn-on	Usually minimal	A major problem. Tubular better than plate heat exchangers
Run time	Long	Short (tubular longer than plate type)
Heat regeneration	∼50%	≥90%
Steam quality requirement	Very high	No specific requirement
Energy requirement	Higher than indirect	
Ability to reach very high temperature (i.e. >145°C)	Capable	Limited
Ability to destroy heat-resistant sporeformers without excessive chemical damage	Better than indirect	
Process control issues	Careful control of water removal after high heat treatment required to prevent concentration or dilution	Need to control pressure increase and temperature differential between product and heating tube or plate as fouling layer builds up
Possibility of contamination from heating medium through pinholes	Nil for sterilising section Possible in regeneration and other indirect heating and cooling	Significant especially with plate heat exchanger
Water requirement	Greater (∼1500 L water per 1000 L product) than for indirect system	
Other process features	Steam injection causes some homogenisation	Tubular is most common UHT heating system; corrugated tubes are used to increase turbulence

(*Continued*)

Table 7.1 (*Continued*)

Parameter	Direct systems	Indirect systems
Product (UHT milk) characteristics		
Flavour (assuming same sterilisation effect)	Mild cooked flavour; chalky if homogenised before high-heat section	Strong cooked flavour
Oxygen level (assuming, no headspace in package, no use of aseptic tank, package not permeable to O_2)	Low (<1 μmL mL^{-1})	High (7–9 μmL mL^{-1})
Sediment formation during storage	Higher than for indirect	
Susceptibility to age gelation	Higher than for indirect	
Plasmin and plasminogen level	Neither completely inactivated	Plasmin generally inactivated but some residual plasminogen may remain
Fat separation	Low, especially for steam injection	More than for direct
Heat indices – HMF, lactulose, furosine	Low	Higher than direct
Undenatured β-lactoglobulin (mg L^{-1})	>700	<200
Folic acid and vitamin C retention	Higher than indirect due to lower oxygen level	Low

Adapted from Datta *et al.* (2002).

pressure of about 0.05 MPa in the filling chamber. Such precautions are necessary to prevent post-sterilisation contamination of the product with airborne bacteria and moulds.

7.9.3 *Factors affecting the quality of UHT milk*

Raw milk quality is affected by: (a) growth of psychrotrophic bacteria and (b) heat-resistant spore-forming bacteria.

Growth of psychrotrophic bacteria

Good quality raw milk is essential for producing UHT milk with a long shelf life. In general, milk destined for UHT processing should be stored refrigerated ($<5^{\circ}C$) for no more than 48 h. Storage at higher temperatures and/or for longer times promotes the growth of psychrotrophic bacteria, which cause the production of lactic acid, reduction of the pH of the milk and also production of enzymes, notably proteases and lipases that can have considerable heat stability.

When the pH is reduced to $\leq$6.5, milk becomes unstable to heat. In UHT processing, such milk readily causes fouling of the heat exchangers, and the final product will show considerable sediment formation (see Section 7.9.4)

The UHT process destroys all vegetative bacteria and most sporeformers but does not inactivate some of the enzymes produced by psychrotrophic bacteria, such as *Pseudomonas* species, i.e. the most common bacterial contaminants of raw milk. Such enzymes are typically produced when the bacterial count exceeds $\sim 10^6$ cfu mL^{-1}. If milk with such bacterial counts is UHT processed, these enzymes, particularly proteinases and lipases, can remain active in the UHT milk. Since UHT milk is usually kept at room temperature and may be stored for several months, even traces of these enzymes can produce noticeable changes, and result in bitter flavour and gelation (due to proteinases) and rancid flavours (due to lipases).

Heat-resistant spore-forming bacteria

Bacterial spores in raw milk present the fundamental challenge for UHT processors. Without such organisms, there would be no need for the heating intensity of UHT to produce a shelf-stable product. The heat-resistant thermophiles, such as *G. stearothermophilus* and *B. licheniformis*, are the most commonly encountered. They can cause the 'flat sour' defect in UHT milk, which is characterised by acid production, but no gas production. However, these thermophiles do not grow in milk under 'normal' storage conditions ($\leq$30°C), and have a growth optimum of $\sim$55°C. They have been known to cause problems if the milk temperature reaches high levels during transportation.

A concern related to raw milk quality is the occurrence of the bacterium *B. sporothermodurans* (IDF, 2000), which produces highly heat-resistant spores. This organism is mesophilic, which means that it can grow at room temperature. Fortunately, it does not appear to cause spoilage other than a slight discolouration of the milk, and seldom reaches counts of greater than 10^5 cfu mL^{-1}. However, it is extremely difficult to remove from contaminated equipment, and has caused the closure of some UHT plants. Because of its heat resistance, its spores may be present in UHT milk and be of little concern. However, the practice of reprocessing out-of-date UHT milk has been shown to enrich the UHT milk with this organism, and cause levels which are of concern.

Scheldeman *et al.* (2004) investigated a case of 'obstinate contamination' of UHT milk from a company, and found two very heat-resistant mesophilic organisms. One was *B. sporothermodurans* and the other was identified as *Paenibacillus lactis*. This was the first time *Paenibacillus* had been isolated from UHT milk, although *Paenibacillus* spores have been previously reported to survive heating at 120°C. *Paenibacillus* spores have been isolated from silage and feed concentrates, which may be the origin of the organism in milk.

Other aspects that can affect the quality of UHT milk are given in the next three sections.

Processing times and temperatures

The major effects of processing on the quality of UHT milk are due to the higher heat load in indirect systems and, to a lesser extent, the lower dissolved oxygen content in directly processed milk, caused by the concomitant extraction of air and water in the vacuum cooling chamber. Table 7.1 contains a summary of the effects of direct and indirect systems on product characteristics.

The two major differences in product characteristics are in flavour and susceptibility to gelation during storage, i.e. age gelation. Indirectly processed milk has a more cooked flavour, and may develop more oxidised or stale flavours due to the higher dissolved oxygen level. However, directly processed milk is more prone to gelation. A major cause of age gelation is proteolysis catalysed by either the native milk plasmin or bacterial proteases resulting from growth of psychrotrophic bacteria, principally pseudomonads, in the milk before processing. Both plasmin and the bacterial enzymes have considerable heat stability; the higher heat load of indirect heating inactivates the proteases much more than does direct heating. While both plasmin and bacterial proteases cause gelation and also bitterness, their modes of action on the caseins are quite different. Bacterial proteases preferentially attack κ-casein in much the same way as chymosin in rennet, while plasmin preferentially attacks β-casein. Thus, the two proteases release different peptides, and this difference can be exploited to determine the cause of age gelation (Datta & Deeth, 2003).

Post-sterilisation contamination

A major consideration in the handling of milk after the high-temperature sterilisation is contamination.This may result from several sources, but two important ones are the seals in the homogeniser (if downstream) and the air supply to the aseptic packaging unit. Kessler (1994) showed that spores trapped under seals had enhanced heat stability, largely attributable to a very low water activity in their microenvironment, and could act as a reservoir of contaminating spores. Flat sour defects due to contamination by *G. stearothermophilus* can arise in this way. Frequent seal changes have been found to be an effective, although expensive, way of minimising such contamination.

Another microbial problem, which has caused problems in several companies in recent years, is the filamentous fungus, *Fusarium oxysporum*. This organism can cause an off-flavour similar to blue-vein cheese in UHT milk within a few weeks, and it also produces gas. It is often detected when packages become swollen or 'blown'. It is a common fungus of plants and soils, and can enter UHT milk packages through contaminated air in the filling machine. Negative air pressures in aseptic filling areas may facilitate contamination of the packaging equipment if there is a source of the fungus nearby. Once the fungus has contaminated a filling machine, it is difficult to eliminate (K. Scrimshaw, personal communication, 2004).

Storage temperature and time

UHT and in-container sterilised milks are subject to considerable chemical and physical changes during storage, although they are more noticeable in the latter (Burton, 1988; Lewis & Heppell, 2000). Each of the changes is dependent on both time and temperature of storage. For example, non-enzymatic browning develops during storage, and proceeds at a faster rate at higher temperatures. It is particularly noticeable above 30°C, and is accelerated in lactose-hydrolysed and sugar-sweetened products.

Age gelation, which is often the limiting factor for the shelf life of UHT milk, is also temperature and time dependent (Datta & Deeth, 2001). However, the temperature dependence is only true up to about 30°C after which gelation is retarded (Kocak & Zadow, 1985) (see Figure 7.6). The exact reason for the retardation at higher temperatures is not known, but may be due to autolysis of the protease involved, excessive proteolysis at the

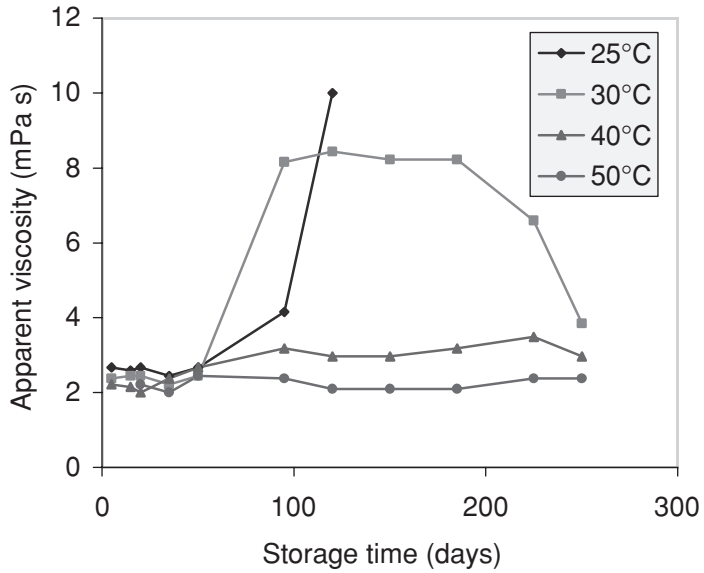

Fig. 7.6 Thickening of UHT milk during storage at different temperatures. Adapted from Kocak & Zadow (1985).

caseins preventing the protein network get from forming or the formation of non-disulphide covalent cross links between the caseins preventing the gel formation (McMahon, 1996).

Oxidation reactions occur, starting with oxidation of sulphydryl compounds produced during heating, then vitamin C and folic acid followed by fats. All these reactions are dependent on the level of dissolved oxygen. This is close to saturation in most products processed by indirect heating, but is reduced in products which have been subject to de-aeration, and in directly treated products subjected to vacuum flash cooling. However, the levels of dissolved oxygen can increase if the sterile milk is stored for some time in an aseptic tank before packaging, if the packaging material is permeable to oxygen or if there is a headspace in the filled package. The headspace volume can vary considerably with the type of package. Perkins *et al.* (2005) found that 1-L Tetra Brik packages to contain an average of ∼8 mL, a 1-L Combiloc package ∼34 mL and a 1-L plastic bottle ∼58 mL. Directly processed milk packaged in the plastic bottles exhibited quite high dissolved oxygen levels (5.8–7.2 mg L^{-1}). The headspace volume can have a major influence on dissolved oxygen levels, and development of volatile carbonyl compounds caused by oxidation (Perkins *et al.*, 2005, 2006).

7.9.4 *Heat stability, sediment formation and fouling*

A major concern with UHT processing is the heat stability of the milk. Milk having poor heat stability can give rise to fouling of heat exchangers and sediment formation, and it would be best to avoid UHT treating such milk. However, there is no test for quickly assessing the heat stability of milk to UHT processing conditions. The much researched heat coagulation test for UHT processing, which measures the time required to coagulate milk at 140°C, is not

easy to perform, and it has not been established that it is useful for predicting susceptibility to sediment or fouling in UHT milk.

Most UHT milk contains a slight amount of sediment, which is not usually sufficient to be a problem (Burton, 1988). It has been found that sediment increases with severity of the treatment, and is present in greater quantities following direct processes (Ramsey & Swartzel, 1984). Zadow (1978) found that little sediment was formed in UHT cow's milk if the pH was kept above 6.62; below this value, sedimentation increased rapidly. In contrast, sedimentation was severe in goat's milk when the pH was below 6.9. Similar trends were observed for concentrated skimmed milk, which were found to be stable above pH 6.55, but below this value, severe sedimentation occurred (Zadow & Hardham, 1981). However, on some occasions, a more voluminous sediment appears, and it is more of a problem in goat's than in cow's milk (Zadow *et al*., 1983; Montilla & Calvo, 1997).

Zadow *et al*. (1983) suggested that ionic calcium may play a role in sediment formation in UHT goat's milk. Up until recently, the only detailed study on ionic calcium in cow's milk at its natural pH was that of White & Davies (1958a,b). A good correlation was found between ethanol stability and ionic calcium for 132 individual cows. Ionic calcium was measured on ultrafiltration permeates derived from each individual milk, using a chemical method. Since then, ion-selective electrodes have been introduced to measure ionic calcium in milk; the most significant of early studies being that of Geerts *et al.* (1983) and more recently by Chavez *et al.* (2004), Lin *et al.* (2006) and Tsioulpas *et al.* (2007a). Thus, there is considerable evidence that ionic calcium varies considerably both in milk from individual cows and in bulk milk, and that this may influence heat stability. However, despite this, its measurement is not routinely practiced as a quality assurance procedure.

One alternative test is the ethanol stability test. By adding equal volumes of different strength alcohol solutions to milk, one can establish the concentration which just fails to cause the milk to coagulate – this is termed the ethanol stability. Pioneering work on understanding factors affecting ethanol stability, and the mechanisms was conducted by Horne and co-workers starting in the 1980s, has been recently summarised by Horne (2003). Shew (1981) recommended that milk should be stable in 74% ethanol to be suitable for UHT processing.

One key question is whether there is a correlation between ethanol stability and stability to UHT processing conditions. The authors' experience with pilot plant and laboratory experiments on cow's and goat's milk suggests that reducing ionic calcium is beneficial in terms of reducing fouling of heat exchangers and sediment formation (Prakash *et al.*, 2006; Boumpa *et al.*, 2008). Also, reducing ionic calcium was found to increase ethanol stability.

Therefore, in situations where sediment formation or fouling is a problem, the following suggestions are offered: routinely monitor pH, ethanol stability and, if possible, ionic calcium in raw milk to establish their contribution to fouling and sediment-related problems. Over time, this should provide data to be able to assess, understand and eventually reduce the problem.

As intimated by Shew (1981), raw milk with an ethanol stability below 74% is likely to be problematic. There are two main reasons why ethanol stability may be low. The first and most likely is a high microbial count, and the second is due to a salt imbalance. The former situation is likely to arise with milk of poor hygienic quality or poor refrigeration. As raw

milk quality deteriorates, i.e. as its bacterial count increases, its pH will fall, which in turn will increase ionic calcium and reduce ethanol stability.

However, as Horne (2003) cautions, milk with a low ethanol stability may still not be of poor microbial quality; it may just have a salt imbalance. In this context, salt imbalance refers to a combination of circumstances that leads to the micelle being made more susceptible to coagulation. For example, any factors which reduce the negative charge, such as concentrations of H^+, Ca^{++}, Mg^{++}, Na^+ and K^+ ions, as well as the proportions of different casein fractions in the micelle. One example is goat's milk, which has a high concentration of ionic calcium compared to cow's milk. Similar detrimental changes may occur to milk when calcium supplements are added, or when the pH is reduced by whatever means. Where permitted, stabilisers, such as disodium hydrogen phosphate and trisodium citrate, may help improve stability; their effect is to reduce ionic calcium, increase pH slightly and increase ethanol stability. Levels used are between 0.05 and 0.2 g 100 g^{-1}, but practical experience should dictate. One possible drawback is more browning, brought about by the increase in pH. This is not likely to show immediately after UHT processing, but may manifest itself during storage, especially when the product is stored at above 30°C.

Overall, it is recommended that ionic calcium, pH and ethanol stability are measured to develop a better understanding of how this relates to UHT plant performance and indicators of fouling and sediment.

It has also been suggested that factors that give rise to sediment formation are also responsible for fouling (Burton, 1988). Much of the research on the mechanism of fouling has focused on the role of β-lactoglobulin denaturation, whereas sediment research has revolved around casein micelle aggregation, in terms of pH and more recently ionic calcium. Of course, denatured β-lactoglobulin is involved through its aggregation with the casein micelle on heating. The mechanism of fouling in UHT plants is usually explained in terms of two types of fouling, A and B (Burton, 1988). Type A deposit is soft and voluminous and forms between ∼75 and ∼110°C in the preheat section; while type B deposit is hard and granular, and forms in the high-temperature sections of the plant. The two deposits differ considerably in composition, with type A being predominantly protein and type B being predominantly mineral, largely calcium phosphate. This mechanism, therefore, focuses on whey protein denaturation and mineral deposition, but does not consider the role of casein. A comprehensive mechanism of fouling and sediment formation involving whey protein denaturation, casein destabilisation and mineral insolubilisation is, therefore, still required.

7.10 High-temperature processing (extended shelf life)

There is a requirement to further increase the shelf life of pasteurised products, both for the convenience of the consumer and to provide additional protection against temperature abuse. However, it is important to avoid the onset of cooked flavour, which results from severe heating conditions. High-temperature pasteurisation has been introduced to meet this requirement. It is a continuous heat treatment between HTST pasteurisation and UHT sterilisation, and is used to produce what has become known as extended shelf life (ESL) milk. It is also known as 'ultrapasteurisation', although this term has a different meaning in some countries. ESL milk can also be produced using non-thermal technologies, such as

Table 7.2 Comparison of HTST pasteurisation, higher pasteurisation and UHT treatment.

Characteristic	HTST pasteurisation	Higher pasteurisation (ESL)	UHT
Heating temp, time	72°C for 15 s	120–135°C for 4–1 s	135–145°C for 10–2 s
Heat index enzyme inactivation	Phosphatase-negative, lactoperoxidase-positive	Phosphatase-negative, lactoperoxidase-negative	Phosphatase-negative, lactoperoxidase-negative
Storage conditions	Refrigerated	Refrigerated	Room temperature
Packaging	Clean	Ultraclean (or aseptic)	Aseptic
Shelf life	10–14 days	30–60 days	>6 months
Flavour	Little heated flavour	Mild heated flavour	Definite heated flavour
Lactulose (mg L^{-1})	~0	20 to ≤40 (Brandes, 2000; Gallmann, 2000; Kjærulff, 2000; Ranjith, 2000)	80–500 (Gallmann, 2000); Ranjith, 2000)
Furosine (mg g^{-1} protein)	~0	200	400–1200 (Gallmann, 2000)
α-Lactalbumin denaturation (%)[a]	~5 (Fredsted *et al*., 1996)	~5 (Fredsted *et al*., 1996)	~30–80 (Elliott *et al*., 2005)
β-Lactoglobulin denaturation (%)[b]	~13 (Fredsted *et al*., 1996)	~22 (Fredsted *et al*., 1996)	~60–100 (Andreini *et al*., 1990; Elliott *et al*., 2005)
Immunoglobulin denaturation (%)	~67 (Fredsted *et al*., 1996)	~100 (Fredsted *et al*., 1996)	~100

[a] Assuming concentration in raw milk = 1200 mg L^{-1}.
[b] Assuming concentration in raw milk = 3000 mg L^{-1}.

microfiltration (Larsen, 1996; Kjærulff, 2000; Hoffmann *et al*., 2006) and bactofugation, but its production by heating processes only is discussed here.

There is no single definition for ESL milk; however, the EU legislation (EU, 1992) states that pasteurised milk, which shows a negative reaction to the peroxidase test, must be labelled 'high temperature pasteurised milk'. In a recent review on ESL milk, Rysstad & Kolstad (2006) used the following definition: *ESL products are products that have been treated in a manner to reduce the microbial count beyond normal pasteurisation, packaged under extreme hygienic conditions, and which have a defined prolonged shelf life under refrigeration conditions* (see also Rysstad & Spikkestad, 2005). These indicate some of the features of ESL milk, and how ESL milk differs from HTST pasteurised and UHT milks. A more detailed comparison is given in Table 7.2.

A range of different temperature–time combinations has been suggested for producing ESL milk. HTST pasteurisation (72°C for 15 s) does not destroy sporeformers or thermoduric non-spore-forming bacteria, such as coryneforms, micrococci and thermoduric streptococci. As discussed above, increasing the temperature of pasteurisation from 72°C to ~90°C destroys some of the thermoduric non-spore-forming bacteria, but has a detrimental effect on shelf life (Schroder & Bland, 1984; Schmidt *et al.*, 1989). Thus, this temperature range is unfavourable for ESL processing. Therefore, an approach is to use temperatures >100°C for very short times. Wirjantoro & Lewis (1996) showed that milk heated to 115°C for 2 s had a much better keeping quality than milks heated at both 72°C for 15 s and 90°C

for 15 s. Ranjith (2000) reported that treatment of milk at temperatures $\leq$117.5°C resulted in high total counts ($>10^6$ cfu mL^{-1}) after 13 days, whereas milks treated at temperatures $\geq$120°C showed counts of $<10^2$ cfu mL^{-1} after storage at 7°C for >40 days. It appears that heating at $\geq$120°C is required to inactivate psychrotrophic spore-forming organisms, such as *B. cereus* and *B. circulans*. The upper temperature limit, which Blake *et al.* (1995) concluded was 134°C, is governed by the heat-induced chemical changes, and can cause flavour impairment. Thus, the most common conditions for ESL heat treatment are in the 120–130°C range for a short time (<1 to ~4 s).

Another approach to produce ESL milk is to use small amounts of a bacteriocin. The addition of small amounts of nisin (40 IU mL^{-1}) was also effective in reducing microbial growth following heat treatment at 72°C for 5 s, and even more effective at 90°C for 15 s. It was particularly effective at inhibiting *Lactobacillus* spp. at both temperatures. Results for milk heat treated at 117°C for 2 s with 150 IU mL^{-1} nisin were even more spectacular. Such milks have been successfully stored for over 150 days at 30°C with only very low levels of spoilage (Wirjantoro *et al*., 2001). Local regulations would need to be checked to establish whether nisin is a permitted additive in milk and milk-based beverages.

A key aspect of the heating conditions to produce ESL milk with a flavour similar to that of pasteurised milks is short heating, holding and cooling times. This is most easily achieved by direct steam heating, either steam injection or steam infusion, for example in the APV Pure-Lac^{TM} system (Fredsted *et al.*, 1996).

For ESL milk, the lowest advisable packaging level is ultraclean, although aseptic packaging is recommended by some authors (e.g. Gallmann, 2000). There is no doubt that the longest shelf lives are obtained with aseptic packaging, but this is achieved at a cost, i.e. the cost of the aseptic packaging equipment installation and maintenance. For this reason, ESL milk is usually packaged in ultraclean rather than aseptic systems.

7.11 Reconstituted and recombined milk products

The issues for reconstituted milk products are similar to those posed by liquid milk products. Most milk powder is now produced by spray drying, which has largely superseded the earlier process of roller drying. The production of milk powder involves a number of processes, including centrifugal separation (for skimmed powder), forewarming, preconcentration and drying. A good account of technology is provided by Kelly (2006).

One of the main characteristics for distinguishing between powders is to the degree of heat treatment, the basis of the whey protein nitrogen index. Low- or medium-heat powders are usually used for reconstituted milk destined for consumption as liquid milk. It is essential to ensure that a high quality milk powder with no off-flavours is used. In terms of minimising problems during heat treatment, it is important to ensure that the powder is well mixed and properly dissolved. There are a number of important properties of milk powders, such as wettability, ability to sink, dispersibility and solubility, which influence this. Usually mixing is achieved at 40–50°C to fully rehydrate the powder. After mixing for about 15–20 min, the milk is often left for another 20 min to remove occluded air, since milk powder may contain up to about 40 mL 100 mL^{-1} of occluded air. Mixing can be done at 5°C, but it will take longer as the powder solubility is lower. Also, oxygen solubility is higher at low temperatures, and the air is less easily removed. Air can also be removed by

vacuum deaeration, which can be incorporated as part of the heat treatment, normally after regeneration and before the homogeniser and the holding tube. Too much air will result in fouling of the heat exchanger, cavitation of the homogeniser and excessive oxidation of the product. Poorly dispersed powder can result in blockage of homogeniser valves and narrow gaps between the plates of the PHE.

Water quality is important – it should be good drinking quality, free of pathogenic microorganisms and an acceptably low hardness, less than 100 $\mu g\ g^{-1}$ of calcium carbonate. Excessive mineral content will jeopardise the salt balance, which may cause problems related to heat stability. Copper and iron contents are important as they promote oxidation and may have an adverse effect on flavour.

A very important property of powders in certain applications is their heat stability. This is especially relevant when they are to be used for UHT milk or concentrated milks. It is related to the variability in the composition and types of protein and minerals, and interactions that take place during processing. Of special interest are stability issues occurring due to changes of season, eating patterns and diet. The underlying causes are not well understood.

Some other important properties of milk powders are bulk density, sensory characteristics, nutritional value and microbial population. The source and composition of the fat used in recombined or filled milks may also influence the sensory characteristics of the milk. In countries where fresh milk and reconstituted milks are available, there is an interest in being able to distinguish between them. This is not a straightforward analytical problem to solve.

7.12 Conclusions

Heating is the major processing treatment applied to milk. In most countries, all market milk and most, if not all, milk used for manufacture undergoes some form of heat treatment. The types of heating vary from the mildest treatment, thermisation, through pasteurisation, high-temperature heating or ESL treatment, to UHT and in-container sterilisation, the most severe treatment. All processes reduce bacterial spoilage, and all but thermisation destroy most pathogenic organisms. The technologies used for heating are very mature and have served and continue to serve the consumer and the dairy industry very well. Considerable research has been carried out on the effects of the different methods and severity of heating on the bacterial flora and the chemical constituents of milk, and these are now reasonably well understood. This understanding has enabled the dairy industry to meet challenges related to heating. For example, there has been increasing consumer demand for minimal processing and natural flavours and, hence, UHT milks with very little cooked flavours. However, the discovery of very heat-resistant bacterial spores in UHT milk some years ago suggested a need for more intense UHT treatment to ensure sterility. These apparently conflicting demands were met by development of technologies capable of very rapid direct heating to high temperatures followed by rapid vacuum cooling. This development was possible through an understanding of the different kinetics of bacterial destruction and chemical reactions. The most recent development has been the introduction of ESL milk to satisfy the demand for a longer lasting market milk with a taste similar to that of pasteurised milk. Further developments in this technology can be expected, possibly in conjunction with some forms of non-thermal processing.

7.13 Appendix

7.13.1 *Some heat transfer properties*

Density (ρ, kg m^{-3}): mass/volume; for solids, must distinguish between bulk density and solid density; for foams, overrun is used. Natural convection is due to density differences.

Specific gravity: mass/mass; dimensionless quantity; the term original gravity is often used in brewing examples.

Viscosity (μ, Pa s or Nsm^{-2}): a measure of the internal friction within the fluid; the ratio of shear stress/shear rate; distinguish between Newtonian and non-Newtonian fluids.

Specific heat (c, J kg^{-1} K^{-1}): the amount of energy required to raise unit mass by unit temperature rise; water has a high value compared to other food components.

Latent heat (h_{fg}, kJ kg^{-1}): the amount of energy required to convert unit mass of material from solid to liquid or liquid to gas at a constant temperature; water has a high value.

Specific enthalpy (H, kJ kg^{-1}): enthalpy $= U + PV$, and specific enthalpy is the enthalpy/mass; at constant pressure, enthalpy changes are equivalent to heat changes.

Thermal conductivity (k, W m^{-1} K^{-1}): this is a measure of the rate of heat transfer through a solid; foods are poor conductors of heat.

Thermal diffusivity (α, m^2 s^{-1}): this measures how quickly a material changes in temperature, when energy is added or removed; it is evaluated from thermal conductivity/density $\times$ specific heat – ($k/\rho c$)

Heat film coefficient (h, W m^{-2} K^{-1}): a measure of heat transfer by convection, within a fluid; compare – gases (low), liquids (intermediate) and condensing vapours (high).

Overall heat transfer coefficient (OHTC) (U, W m^{-2} K^{-1}): a measure of the overall heat transfer performance of a heat exchanger, which accounts for all the individual resistances to heat transfer; high OHTC values are desirable, and OHTC is reduced by fouling.

7.13.2 *Definitions and equations*

Temperature conversion

$^\circ C = (^\circ F\text{-}32) \times 0.56$

$K = ^\circ C + 273.15$

Temperature difference

$^\circ C = ^\circ F \times 0.56$

$1^\circ C = 1K$

Energy units

4.18 J = 1 calorie

1 BTU = 1.055 kJ

1 therm = 10^5 BTU

1 kWh (unit) = 3.6×10^6 J or 3.6 MJ

Heat exchanger design: rate of heat transfer $Q = UA\Delta\theta_m$

Q = duty (Js^{-1}); U = overall heat transfer coefficient ($Wm^{-2}\,K^{-1}$); A = surface area (m^2), $\Delta\theta_m$ = log mean temperature difference (K).

Batch pasteurisation time $(t) = \dfrac{Mc}{AU}\ln\left(\dfrac{\theta_h - \theta_I}{\theta_h - \theta_f}\right)$

M = mass (kg): c = specific heat ($J\,kg^{-1}\,K^{-1}$); A = surface area (m^2); U = OHTC ($Wm^{-2}\,K^{-1}$); h = heating medium, I = initial, f = final temperatures.

Regeneration efficiency $= \dfrac{\text{Energy supplied by regeneration}}{\text{Total energy required if there was no regeneration}} \times 100$

Values may be as high as 95%; high values reduce energy costs, but increase capital costs and reduce heating rates.

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