SDT Society of Dairy Technology

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1. Introduction

The objective of the handbook is to provide a readily available source of essential information about the whole dairy sector, which includes both production and processing sub-sectors.

The handbook will be useful not only to producers and processors but also to farmers wishing to diversify into processing and service providers such as dairy consultants who will appreciate the wide range of topics covered. It is considered particularly useful for students and for international development purposes.

The handbook was originally conceived by John Hambly, a dairy consultant who spent his career in both milk production and processing, in the UK and abroad.

The main contributors to this handbook were Society members, including: Joy Alexander, Chris Askew, Dr Ken Burgess, Dr Alistair Grandison, Dr Phil Kelly, Merfyn Lewis, Dr Mike Lewis, Brian Peacock, Eurwen Richards, Nigel Stevens, John Sumner, Soeren Vinsild, Dr. Stephen Walker, Maurice Walton, Dr Liz Whitley and Andrew Wilbey.

Much of the data in this book were sourced from the Society of Dairy Technology's technical book series, published by Wiley. The books are designed to provide an invaluable resource for all those involved in the dairy industry, from practitioners to technologists, working in both traditional and modern large-scale dairy operations. The handbook includes a range of recommended further reading, and some illustrations were also taken from the TetraPak Dairy Handbook and the SPX Handbook.

By publishing this handbook in electronic form, the Society hopes that it will provide an economic and efficient source that can be updated periodically as the technology of milk processing continues to advance. This third edition continues the principle of being a work in progress; suggestions and contributions will always be welcomed.

Andrew Wilbey
Handbook Editor

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2. Milk Production

This chapter describes in general terms the production side of the UK dairy industry. It will describe the political and structural changes witnessed in recent years, discuss the trends in housing, milking, dairy cow breeding and feeding, and consider a number of animal health and welfare issues which impact the processing and marketing segments of the industry.

A historical perspective

Milk marketing

As a result of the great depression of the 1920s and a catastrophic fall in dairy product prices, the Agricultural Marketing Act was passed in 1931 by the Government of the day. It introduced the concept of producer controlled marketing schemes with compulsory membership. A marketing scheme for milk was put in place in 1933.

The scheme was administered across the UK by a number of Milk Marketing Boards (MMBs). Five were established; one in Northern Ireland, three in Scotland and one for England and Wales, the latter being by far the largest. Each had statutory powers for the purchase and sale of all the milk produced in its area.

A radical change took place in 1994 when, after some 60 years of being a major influence within the UK dairy industry, the MMBs ceased their statutory monopoly of buying all wholesale milk off farms. Farmers were free to sell their milk to any buyer, including direct to dairy companies.

Milk Marque, a farmer co-operative successor to the MMB in England and Wales, was replaced about five years later by three co-operatives following a ruling by the Monopolies and Mergers Commission. However, many farmers had chosen to sell their milk direct to milk processors and in the intervening years, structural change has continued as co-operatives and dairy processing companies had either merged or left the industry. A number of smaller, specialist farmer-owned co-operatives were also set up at the time of de-regulation, some of which remain in business today.

Structural change – dairy farming

The UK is the third-largest milk producer in the EU after Germany and France, and the tenth-largest producer in the world. Milk accounted for 17.8% of total agricultural output in the UK in 2014, and was worth £4.6bn in market prices. In the ten years to 2016, the total number of UK dairy cows has fallen by 27% but despite that, the UK produced 14.6 billion litres of milk in 2014, the highest annual figure since 1990.

In parallel to the changes described above, dairy farming in the UK has and continues to experience rapid and remarkable structural change. Producer numbers have been declining at an average of between 3% and 4% per year throughout the period (Table 2.1). In some recent years the decline in numbers has been greater than average, though that has provided opportunities for others to expand.

Table 2.1 Numbers of UK dairy farmers (sources: MAFF/Defra, DairyCo, AHDS)

Year	Producers	Dairy cows ('000)	Herd size	Milk Yield (litres/cow)
1960	151, 625	3,165	20	3,380
1970	100, 741	3,244	30	3,750
1980	56,247	3,224	51	4,670
1990	41,248	2,846	67	5,145
2000	29,000	2,350	80	5,800
2010	16,154	1,850	115	7,096
2015	13,815	1,895	133	7,910

Sources: Defra, AHDB

The declining trend in the number of milk producers is not unique to the UK but it is common to all developed dairying countries as mechanisation and automation replaces labour on dairy farms. Total UK milk production has also been declining since 2003/4 but has recently shown a welcome recovery, as illustrated in Figure 2.1.

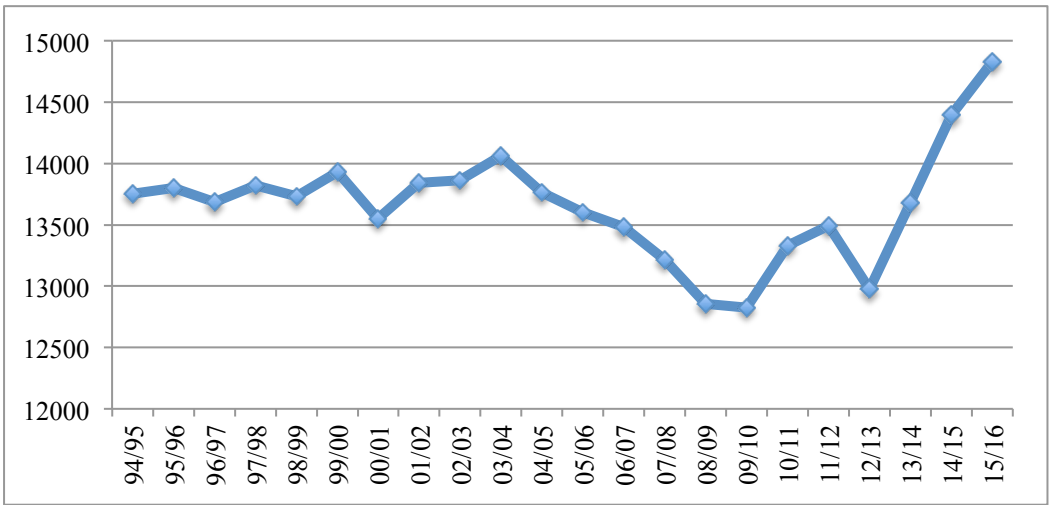


Fig. 2.1 UK total milk production (ML per year) 1994–2016 (source: dairy.ahdb.org.uk)

Herd size and milk yield

Whilst the number of farms has declined, the average herd size has increased significantly and with improving milk yields. At the same time, UK dairy cow numbers continue to fall. In 2010 there were 1.85 million dairy cows, having fallen by 6.7 % in the previous five years.

The UK has experienced real improvement in genetics, measured at about 2% per year throughout recent decades. The increase in cow yield is a result of better genetics linked to improvements in nutrition and better herd management. Figure 2.2 shows the relationship between individual cow milk yields and cow numbers.

Looking to the future, it is expected that the reduction in the numbers of dairy farms will continue whilst the average herd size will increase further.

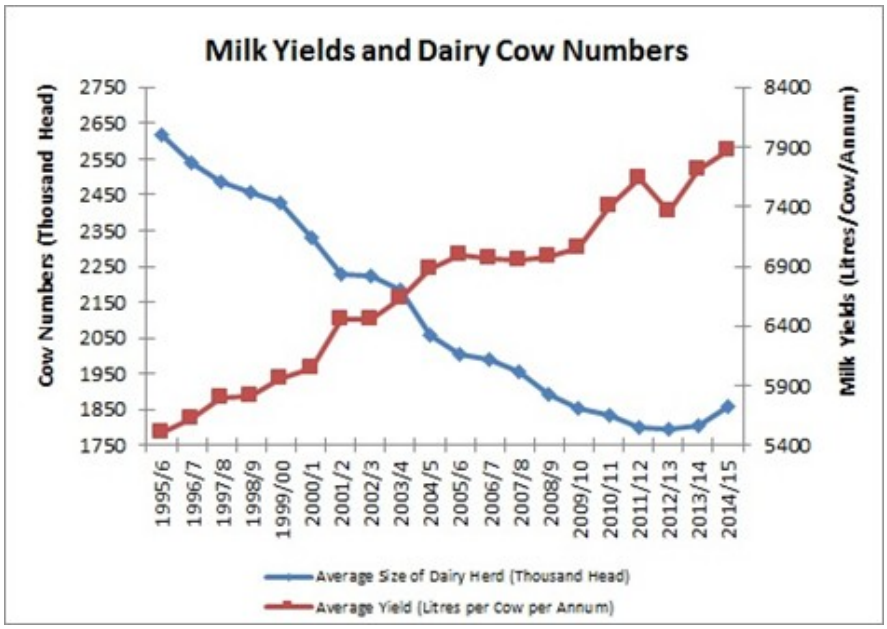


Fig. 2.2 Relationship between individual milk yields and cow numbers (source: dairyco.net)

Political changes

In addition to deregulation of the industry in 1994, there have been significant political changes as part of Common Agricultural Policy (CAP), which have been drivers for change in dairy farming. The major changes were:

Milk quotas – The introduction of milk quotas in April 1984 resulted in controls on farm milk output and limitations on expanding farm businesses. At the time EU production far outstripped demand, the milk quota regime was one of the tools introduced for overcoming these structural surpluses. After more than 30 years, the EU milk quota regime was abolished at the end of March 2015.

Agenda 2000 – Introduced cross compliance amongst other reforms.

Mid-term review – The reforms continued including a whole new farm support system in 2003 called the Single Farm Payment (SFP). The SFP scheme will be reviewed in 2013 when CAP will be further reviewed.

Health Check 2008 – A policy switch from output to environment, animal disease, and food safety issues. The measures included the phasing out of milk quotas and abolition in 2015. Quota allocation is to be increased by 1% every year to allow a "soft landing".

Legislative requirements for milk producers

Dairy farm hygiene

The European Union food hygiene legislation, which came into effect on 1 January 2006, set out the duty of food businesses to produce food safely and to achieve consistency.

The Food Standards Agency is responsible EU food hygiene legislation, which covers the whole food chain from farm to fork. The Food Safety and Hygiene (England) Regulations 2013 relate to milk production holdings and the subsequent supervision and inspection. The inspections include the health and cleanliness of the animals, hygiene during milking and controls on raw drinking milk. They are supervised by the FSA Dairy Hygiene Inspectors with similar arrangements in place for Wales, Scotland and Northern Ireland.

A simple and practical dairy hygiene booklet (Milk hygiene on the dairy farm guide – a practical guide for milk producers) has been produced to reflect the change in delivery of official controls and to assist milk producers to achieve the standards of hygiene required to conform with the legislation.

Farm assurance

Additional checks are carried out on farms that are members of the Assured Dairy Farms Scheme (a Red Tractor assurance scheme). Farms are audited every 18 months against the Scheme standards.

Veterinary medicines

The use of veterinary medicines on farm animals is controlled under European law. The legislation aims to protect consumers, by stopping unacceptable levels or concentrations of residues from veterinary medicines getting into the food chain. Maximum Residue Limits (MRLs) and withdrawal periods are set as part of achieving this objective.

Farmers are also required to keep records of the veterinary medicines used on their animals and to report any adverse reactions to a veterinary medicine. There are also rules about the movements of livestock, which help to prevent the spread or outbreak of animal diseases. *(See below "The British Cattle Movement Service* (BCMS)*").*

The British Cattle Movement Service (BMCS)

Cattle farmers are required by law to keep a record of animals born, arriving and leaving, or dying on their farms and to notify BCMS of all incidents. The Department for Environment, Food and Rural Affairs (Defra) is responsible for cattle identification and tracing issues in England. The Scottish Government is responsible for these issues in Scotland with the Welsh Assembly Government responsible for Wales.

The main role of the BCMS is to maintain a cattle-tracing database, issue cattle passports and process information about cattle movements received from farmers. The database makes it possible to check which animals are present on a holding, to check easily where cattle came from and where they have been during their lives and importantly, to trace cattle more easily if there is a disease outbreak. The system gives buyers greater assurance about an animal's history

Cattle breeds and breeding

In recent decades the UK cattle population has been dominated by black-and-white animals. The traditional black-and-white breed is the British Friesian. The ability of the Holstein breed to make best use of grass and conserved feed and produce high yields, attracted breeders, and Holstein sires were increasingly used on British Friesians. In recent years there has been a reversal in the trend, due in some degree to consumer concerns and problems associated with poor fertility.

Today there are herds of pure-bred British Friesians and Holsteins but the majority of black-and-white cattle today will be Holstein Friesian crosses. A key milestone in the cattle breeding industry was the merger of the Holstein Friesian Society and British Holstein Society into Holstein UK and Ireland at the end of the 1990s.

Other traditional dairy breeds of cattle continue to thrive, albeit in relatively small numbers. Amongst them are the Channel Island breeds including the fawn coloured Jersey, perhaps the oldest dairy breed in the country, and the cream coloured Guernsey, both of which are known for their high butterfat and protein content of milk. With its distinctive red markings, the Ayrshire breed is easily recognised as the reddish coloured shorthorn and is also m aking a huge resurgance.

Housing systems

Historically, dairy cows were housed and milked in cowsheds, sometimes known as byres or tied stalls. The need to increase herd size and make more efficient use of farm labour encouraged the change to "loose" housing of cows and parlour milking. Defra's Farm Practice Survey for 2010 reports that over 80% of cows were housed in cubicles whilst 17% were housed in straw yards. Relatively few cows are house in traditional cowsheds and are likely to be in small herds.

Cubicles

The average dairy cow needs to lie down for around 12 to 14 hours each day to maximise milk production. Cubicles are designed to allow cows full freedom of movement when lying down or rising from a lying position. Comfortable bedding surfaces provided by amply supplies of straw, sawdust or sand, encourage cows to lie down for the optimum length of time. Rubber mats placed on the surface of the cubicle floor, albeit expensive to buy, have been shown to encourage longer resting periods.

Management of cubicles, that is the frequent removal of slurry and replenishment of clean bedding, are key elements of good practice in the production of clean milk and control of mastitis.

Straw yards

Housing dairy cattle on straw-bedded yards can provide a particularly comfortable environment for dairy cows. They do however require high standards of management as soiled straw bedding tends to heat-up, providing an ideal environment for many pathogens. Straw used for bedding must be clean, dry and free from fungi, yeasts and moulds.

For many farm businesses, the cost of straw for bedding and the labour required for daily management make straw yards unattractive, although for dairy farms in arable regions or with an arable enterprise, straw may be cheap and readily available. Straw yards also require less equipment, simpler buildings and slurry handling facilities are minimal. Management of the straw yard is critical. There should be careful attention to stocking density within the yard to ensure sufficient space requirements per cow.

Milking systems

There is no public central record of the numbers and types of milking parlours in use on UK farms. The major types are given below.

Herringbone milking parlours

Herringbone parlours remain the most popular. Cows are milked in batches resulting in high cow throughput and efficient use of labour. The size and arrangement of herringbones have changed in recent years to accommodate larger herd sizes and the need to reduce the time taken for milking. As a result, the trend of recent years has been to parlours with more milking units to allow a greater throughput of cows in a given time. A parlour with 36 stalls and 18 milking units is not considered very large today, with many having considerably more.

Rapid exit parlours

A development of the herringbone is a rapid exit parlour, where the breast rail is lifted up after milking and all cows can leave the parlour simultaneously thereby reducing the time to milk each batch of cows and improving throughput.

Rotary milking

Rotary milking parlours offer benefits to herds with more than 500 cows. As the name implies, cows stand to be milked on a raised, circular platform that rotates. There are differences in the basic design with the "abreast" and "herringbone" formations being the most popular. Cows stand side by side in "Abreast" rotary parlours with the operator working on the outside of the moving circular platform. For the rotary herringbone, the operator stands in the centre of the moving ring shaped platform. In both cases, the operator works from a single position at floor level as the circular platform slowly rotates past. The direction and speed of rotation can be varied according to milk yield. An installation with forty milking units is not considered to be large and the justification is again labour efficiency.

Automated milking systems

Automated Milking Systems (AMS) are commonly known as robotic milking. Attempts to minimise time management constraints has led to the development of AMS in which cows volunteer to be milked. All the processes involved with milking, teat preparation, applying and removing milking units and so on are carried out robotically, without the need for an operator. Voluntary milking allows the cow to decide its own milking time and interval, rather than being milked as part of a group at set milking times. AMS requires complete automation of the milking process, as the cow may elect to be milked at any time during a 24-hour period. Typical capacity for an AMS is 50 to 70 cows per milking unit, which means that this expensive system is more likely to be installed on average sized herds.

Automation in milking

As part of the drive to improve labour efficiency it is possible to automate most elements of the milking process. Powered gates can control the movement of cows towards the milking parlour, cows can be automatically identified when entering the parlour, individuals can be fed a pre-determined amount of concentrate food, milk yield can be automatically recorded, milking clusters can be removed automatically after each cow is milked and post milking teat spraying systems are available for mastitis control. Automatic in-line milk sampling and testing is a new development. Teat preparation and milking cluster attachment are also automated in an AMS.

Data collection

As the technology of milking systems becomes more sophisticated, there follows the opportunity to install automatic recording devices within milking parlours, linked to computer management systems. Such systems, linked through management software to a computer, are in commercial use on many farms, providing valuable management information.

Nutrition

Financial effects

Feeding is the largest dairy herd cost, approximately 50% of the variable costs of milk production, and almost certainly offers the greatest potential for improving profitability on most farms. Compared to breeding or other key aspects of herd management, most of which have a longer-term impact, the financial effects of feeding improvements are generally evident within a relatively short space of time.

Nutritional requirements

Meeting the nutritional needs of cows through their lives as completely and cost-effectively as possible is the primary purpose of dairy feeding. Nutrient requirements vary with the stage of lactation and gestation. During early lactation, milk production increases rapidly. During this period cows have difficulty eating enough to meet the nutrient needs for milk production, especially for energy, and body tissue will be mobilised to meet energy requirements for milk production. Managing high yielding cows to meet their energy intake requirements for peak milk is therefore a major challenge for dairy farmers.

Feeding strategies

The milk yield potential of individuals or batches of cows grouped according to milk yield or stage of lactation, can be readily predicted based on individual cow milk recording information. Feeding standards are used to help guide nutritionists and livestock producers to formulate rations designed to meet the nutrient requirements of dairy cows performing at different levels. Good nutrition is a critical factor in determining cow health and fertility.

Calf rearing

Rearing dairy herd replacements represents a major investment by dairy producers in the future of their enterprise. Calf mortality and health problems in general, represent a significant economic and welfare cost on many farms and to the UK industry generally. A sufficient intake by new-born calves of colostrum in the first six hours is vital to good calf health in the period before weaning. In addition to the valuable nutritive properties, colostrum also contains antibodies against a range of disease-causing organisms.

Heifer rearing

Calves are commonly weaned at about 8 weeks of age having been reared on whole milk and/or a milk replacer. Milk replacers offer the benefit of nutrient consistency. After weaning the feeding and management of heifers is geared around achieving specified live weight targets with the aim of calving at 23-25 months of age. Feed conversion is very high when animals are young and good feeding strategies will result in better health and, in due course, higher milk yields.

Milk quality, animal health and processing

The chemical and microbiological constituents of milk influence product processing. The milkfat and protein contents of bovine milk are influenced by breed and nutrition, as described above. The microbiological quality is influenced by good hygiene during milking, by effective milk cooling and high standards of plant cleaning. Bacteria can also be present in raw milk as a result of milking cows with mastitis.

Mastitis

Mastitis is the most frequent and costly disease of dairy cows as it results in lower milk yields and milk quality. It is also a major cause of culling. Mastitis is an inflammation of the mammary gland caused by a wide range of pathogenic microorganisms. It is a complex disease and may develop in an

acute, sub-acute or chronic form. Common to all these forms is the main symptom – increased somatic cell counts; this increase is a response to irritation mostly caused by invasion of the udder by mastitis-causing bacteria.

Regulation (EC) No. 853/2004 contains standards for plate count and somatic cell count (SCC) levels for raw milk to be further processed. The criterion for SCC is ≤ 400 000 mL^{-1}.

There are well proven control measures available to limit mastitis infections and considerable progress has been made in reducing the national average somatic cell count, as illustrated in Fig 2.3.

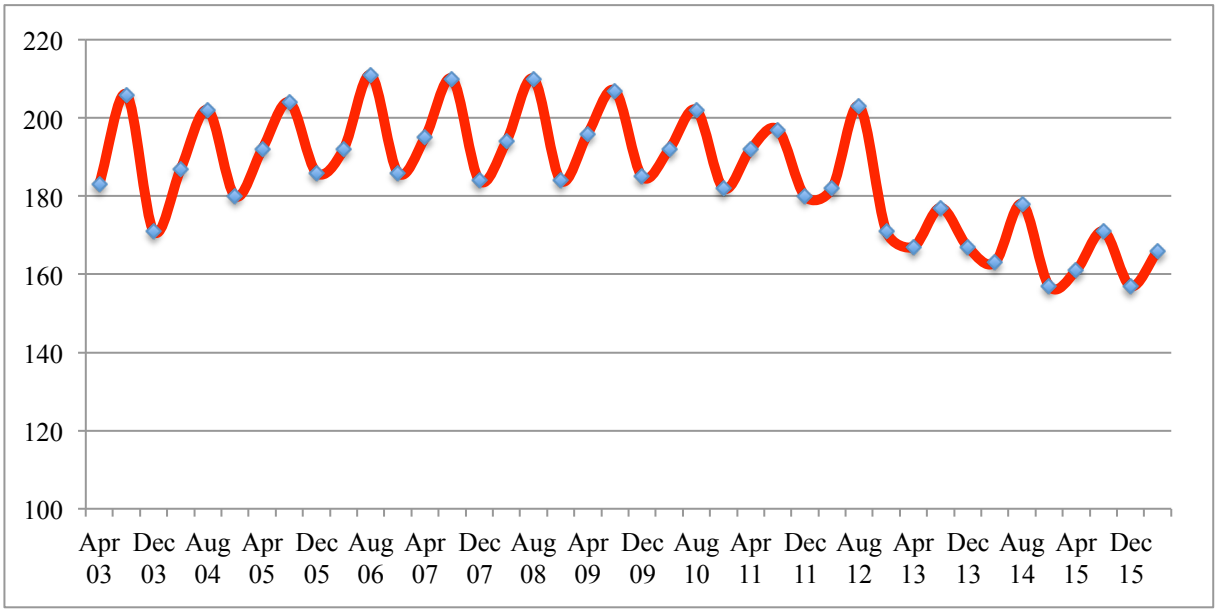


Fig. 2.3 National SCC averages (counts in thousands per mL) 2003–2016 (source: dairy.ahdb.org.uk)

The average SCC for August 2017 was 160,000, suggesting some levelling-off. Steady progress has also been made in reducing bacterial counts, as shown by the Bactoscan data in Fig 2.4.

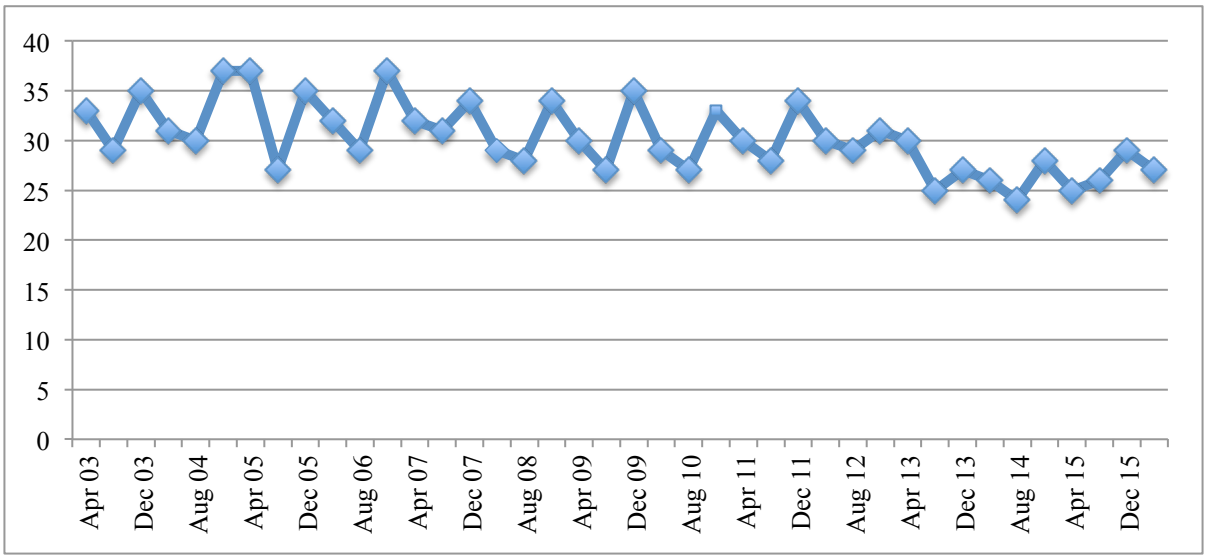


Fig. 2.4 National Bactoscan averages (counts in thousands per mL) 2003–2016 (source: dairy.ahdb.org.uk)

Summary

The chapter has presented little more than a brief description of milk production on the farm and reflected on the structural, political and technical changes that have taken place over recent decades. Structural change will continue, new technologies will become available to assist farmers in improving their competitiveness. Providing a safe, high-quality and nutritious dairy product depends upon all links of the production chain, but the initial responsibility rests with dairy farmers that provide the raw milk.

3. Dairy chemistry: an introduction

Overview of milk components

The nutritional value of milk is very high, deriving from the presence of the three major food macronutrients (fat, protein, carbohydrate) and a range of vitamins and minerals. The main constituent of milk is water (around 87%).

Milk Fat

Chemistry

The average fat content of milk in the UK is approximately 4%. Over 98% of the fat in milk exists as triglycerides; glycerol molecules to which three fatty acid chains are attached. The properties of these triglycerides depend to a large extent on those of the individual fatty acids themselves, their chain length (number of carbon atoms) and the number of unsaturated bonds they contain.

Shorter chain fatty acids, e.g. butyric acid, C4:0, are specific to the milk of ruminants like cattle, and give the characteristic rancid flavour of bovine milk fat when it is hydrolysed by lipases (fat-splitting enzymes).

Longer chain fatty acids have a significant impact on the hardness of milk fat. For example, a higher proportion of palmitic acid (C16:0) will give a harder fat while a higher proportion of the unsaturated oleic acid (C18:1) will give a softer fat. Generally, milk fat from summer milk (mainly grass fed) is softer than milk fat from winter milk (mainly silage and concentrate fed).

The presence of large numbers of different fatty acids in milk fat also accounts for the wide range of temperature over which it melts. Milk fat is fully melted, i.e. liquid, at $\geq 37°C$.

Structure

Most of the fat in milk is physically in the form of small globules of average diameter 3 to 4 μm, range 0.1 to 20 μm. The fat globules are stabilised by a very thin (10 nm) membrane which covers their surface, the milk fat globule membrane (MFGM). The MFGM is comprised mainly of protein and phospholipid.

Separation and homogenisation

In raw milk, the fat naturally has a tendency to rise to the surface (creaming) as a result of the difference in density between the fat and the skimmed milk in which it is suspended. This creaming effect can be an advantage if the objective is to produce cream from milk, but a disadvantage if the objective is a consistent and homogeneous product. The pros and cons of milk fat creaming are addressed industrially by separation and homogenisation processes.

In the industrial production of cream, the natural creaming process is greatly accelerated by increasing the gravitational force, raising the separation temperature and by minimising the distance that the fat globules have to travel. Commercial separators are high-speed mechanical centrifuges containing stacks of concentric discs rotating in excess of 5,000 rpm. The heavier skimmed milk phase is forced to the outside by the centrifugal force, while the lighter fat globules move towards the inside.

In contrast, the rate of creaming can be significantly lowered by reducing the size of the fat globules. This is achieved by the process of homogenisation, whereby milk is pumped under high pressure through very narrow valves. The homogenisation process is usually carried out at 55°C to ensure that the fat in the globules is liquid. Homogenisation can reduce the average fat globule size to less than 1μ, at the same time causing a large increase in the surface area of the fat globules. The shortfall of fat globule membrane material is made up by the adsorption of milk proteins onto the fat globule surfaces.

Milk protein

Chemistry

The average protein content of milk in the UK is approximately 3.3%. This overall protein content (total nitrogen (TN) x 6.38) is broken down approximately as follows:

Caseins (76%)
Whey proteins (18%)
Non-protein nitrogen, NPN (6%)

The major milk proteins, caseins and whey proteins are distinguished by their solubility at pH 4.6: caseins are insoluble at this pH, whereas whey proteins are soluble.

There are four main types of casein in milk protein; α_{s1}, α_{s2}, β and κ. The relative sensitivity of each to calcium precipitation has a major impact on the structure of casein in milk (see below) and on the response of casein to treatment with the enzyme chymosin (rennet).

The main whey proteins are β-lactoglobulin and α-lactalbumin. While they are soluble at pH 4.6 in cold milk, their protein structure is very vulnerable to change on heat treatment (denaturation), which can lead to them becoming insoluble (or precipitating) and/or reacting with some of the caseins when milk is heated.

Structure

The most important protein structures in milk are those of the caseins. Most of the casein present in milk exists in the form of casein micelles, colloidal particles of diameter 10 to 100 nm. The casein micelles themselves can be thought of as being made up of smaller "sub-micelles" (containing between 10 and 100 casein molecules) held together within a "cement" of calcium phosphate chains.
κ-casein is the least sensitive of the four casein types to calcium precipitation and tends to be found on micellar surfaces, where it exhibits a protective, stabilising effect on the other three types.

The significance of the micellar structure of casein, and the position of κ-casein on the surface of micelles, are key to the micelle's response to treatment with the enzyme chymosin (rennet).
The chymosin splits the κ-casein into para-κ-casein (at the same time eliminating its stabilising ability against calcium) and a smaller glycomacropeptide (GMP), also referred to as a caseinomacropeptide (CMP). This reaction is the basis for coagulum formation in cheese making (see Cheese Section later).

Economics

While much has been claimed for vegetable alternatives to milk, the economics of these 'milks' as a protein source have received less attention and Table 3.1 makes an interesting comparison.

Table 3.1 Protein cost comparison between 'milk' sources (Adapted from Lewis M. (2017) The case for milk. *Dairy Industries International,* **82**(6), 34–37.)

Milk source	Price (£/L)	Protein (g/100 mL)	Cost (£/g protein)
Bovine	0.65	3.2	0.0203
Soy	1.40	3.6	0.0389
Oat	1.40	0.8	17.5
Almond	1.50	0.5	30
Coconut	1.40	0.2	70
Rice	1.40	0.1	140
Oat			

Lactose

Chemistry

The average lactose content of milk in the UK is 4.7%. Lactose also accounts for some 70% of the solids in whey, and up to 85% of the solids in the permeate streams from membrane processing of whey.

Lactose is a disaccharide made up of the two monosaccharides, galactose and dextrose (glucose), joined by a β-linkage. Lactose is a reducing sugar and as such will undergo the Maillard reaction when heated with proteins, producing a browning effect and a range of "cooked" flavours.

Characteristics

Lactose has a relatively low sweetness (≈ 30% of that of sucrose) and has the ability to adsorb and bind flavours and aromas. The sweetness of lactose can be increased significantly by enzymic hydrolysis of lactose into its constituent monosaccharides.

Lactose is also relatively insoluble compared with sucrose, and small crystals of lactose can cause a "sandiness" defect in some frozen and concentrated dairy products.

One of the most important characteristics of lactose is its utilisation as a fermentation substrate. Lactic acid bacteria have the ability to convert lactose to lactic acid, the main process in the production of fermented dairy products such as yoghurt and cheese.

Minor constituents

Minerals

The average mineral content of milk in the UK is 0.7%. Milk contains all 22 minerals necessary to the human diet, with calcium and phosphorus predominating. The latter are very important in contributing to the protein structure both in milk and a range of dairy products.

Vitamins

Milk is an important source of a wide range of fat-soluble and water-soluble vitamins:

Fat-soluble; vitamins A, D, E, K

Water-soluble; vitamins B_1, B_2, B_6, B_{12}, niacin and pantothenic acid plus low levels of C.

Levels of vitamins will vary seasonally and the quantities present in processed milk and milk products will also depend on the processes employed.

Other minor constituents

Milk contains up to 0.2% of organic acids such as citric and lactic acids, which contribute to milk's slightly acidic pH of approximately 6.7.

Milk also contains a number of enzyme systems, the most important of which are lipases and proteases capable of hydrolysing milk fat and protein respectively. Another important enzyme in milk is alkaline phosphatase, which is inactivated at pasteurisation temperatures *(see Milk Processing section later)*. Testing for its presence in heat-treated milks is a well-established indicator of effective pasteurisation.

Further reading

Fox, P.F. & McSweeney, P.L.H. (1998) *Dairy Chemistry and Biochemistry*. Blackie Academic, London.

Griffiths, M. (ed.) (2010) *Improving the Safety and Quality of Milk*, Volume 1. Cambridge:Woodhead Publishing.

Fox P.F & McSweeneyP.L.H &. (eds.) (2006) *Advanced Dairy Chemistry Vol. 2: Lipids.* 3rd edition, Springer, London.

McSweeney P.L.H & Fox P.F. (eds.) (2009) *Advanced Dairy Chemistry Vol. 3: Lactose, Water, Salts and Minor Constituents.* 3rd edition, Springer, New York.

McSweeneyP.L.H & Fox P.F. (eds.) (2013) *Advanced Dairy Chemistry Vol. 1A Proteins: Basic Aspects.* 4th edition, Springer, London.

McSweeneyP.L.H & O'Mahony J.A. (eds.) (2016) *Advanced Dairy Chemistry Vol. 1B Proteins: Applied Aspects.* 4th edition, Springer, London.

Tamime, A. (ed.) (2009) *Milk Processing and Quality Management* (Society of Dairy Technology Series). Wiley-Blackwell, Oxford.

Walstra, P.F., Wouters, J.T.M. & Guerts, T.J. (2006) *Dairy Science and Technology.* 2nd edition, CRC/Taylor & Francis, London.

4. Dairy microbiology: an introduction

Overview of milk microbiology

As can be seen from the previous section on dairy chemistry, milk has a very high nutritional value: this is of importance not only to consumers, but also to microorganisms and as such milk is able to support the growth of a wide range of microorganisms. These microorganisms include pathogenic and non-pathogenic bacteria as well as yeasts and moulds and, broadly speaking, microorganisms gain access to milk from three main sources; the cow, the handler and equipment.

The cow as a source of microorganisms

Milk in the udders of healthy cows is generally free from microorganisms but as the milk enters the teat canal it may become contaminated with bacteria, yeasts and moulds that have ingressed from the surface of the animal or from bedding and the environment. Examples of such species include *Staphylococcus aureus* from the skin, *Escherichia coli*, *Salmonella* and coliform organisms from the faeces plus *Listeria monocytogenes*, *Yersinia enterocolytica* as well as *Bacillus* and *Clostridium* spp. from bedding and the environment. The external surfaces of the udder can be very important sources of milk contamination as faeces, mud and bedding can all stick to the udder and washing may not reduce the loading significantly. It will be noticed that all of the species listed above may be pathogenic and in addition the presence of *E. coli* 0157:H7 from faecal contamination has serious public health implications.

There are a number of bacteria (Table 4.1) that may be derived from udder disease, particularly those organisms which cause mastitis. Many of these are pathogenic to humans as well as the cow and so animals showing signs of mastitis and other illness should be treated immediately and their milk excluded from the bulk tank. Apart from the direct risk of antibiotic residues to human health, there is also the risk following development of antibiotic resistant enteric organisms in the cattle. More recently, attention has focused on the occurrence of *Mycobacterium avium* subsp. *paratuberculosis* in the milk supply. This organism is responsible for Johne's Disease in cattle and can may be implicated in Crohne's Disease in humans. Its potential presence in raw milk has led to an increase in the pasteurisation retention time from 15 to 25 seconds.

Table 4.1 Diseases of the cow and causative microorganisms

Disease	Causative organism
Mastitis	*Staphylococcus aureus* *Streptococcus uberis* *Streptococcus agalactiae* *Escherichia coli* *Listeria monocytogenes*
Johne's Disease	*Mycobacterium avium* subsp. *paratuberculosis*
Tuberculosis	*Mycobacterium bovis* *Mycobacterium tuberculosis*
Brucellosis	*Brucella abortus*

Cows are also susceptible to viral infections that can affect yields as well as being a threat to their lives, e.g. foot and mouth, blue tongue.

The handler as a source of contamination

Automated milking systems have greatly reduced the potential for handlers to contaminate milk, but good practice recommends that normal food safety precautions are applied and that handlers suffering from microbial illness are not involved in the milking process.

Equipment as a source of contamination

Assuming that the milk has been derived from healthy animals and that animal management and milking practices are good, the milk should be relatively pathogen free. However, a number of non-pathogenic microorganisms may enter the milk via the equipment and water supply. Table 4.2 gives a range of microorganisms that may be derived from equipment both within the milking environment and the processing dairy. Pasteurisation will remove large numbers of these from the supply but a number are able to survive pasteurisation (thermoduric species) and, since survival is based on a logarithmic reduction, then the greater the contamination pre-process the greater the potential number of survivors.

Water supplies have the potential to contaminate equipment significantly and so the water source is very important. Species such as pseudomonas, *E. coli*, coliforms and spore formers may all occur in water and in particular from natural supplies such as spring water and borehole supplies.

Table 4.2 Microorganisms that may contaminate equipment

Organism	Likely sources
Pseudomonas spp.	Raw milk, water, poor cleaning
Campylobacter jejuni	Raw milk, untreated water
Escherichia coli	Raw milk, untreated water, handlers
Bacillus spp.	Raw milk, poor cleaning
Lactobacillus spp.	Raw milk, poor cleaning

The contamination of milk with highly heat resistant spore-forming organisms such as *Bacillus* spp. and *Clostridium* spp., which may form spores, along with heat resistant lactobacilli is an important area as these organisms can subsequently be found in pasteurised milk. These may lead to defects such as souring or bitty cream, the latter being caused by *Bacillus cereus*. It is important to ensure that cleaning of milking equipment is effective and that the build-up of milk scale and biofilms is prevented as these can both offer harbourage to microorganisms.

Post-process contamination

Once processed, the most important source of contamination is the equipment, as a result of poor cleaning or contaminated water supplies. Cleaning processes are discussed elsewhere in this publication and it is important to recognise that ineffective cleaning can lead to contamination with a range of genera including pseudomonads, bacilli, coliforms and heat resistant lactobacilli. Open equipment such as cheese vats may also become contaminated with yeasts and moulds and yeasts such as *Kluyveromyces marxianus* var. *lactis*, *Candida famata*, and *Candida lipolytica* may be found in products. Whilst non-pathogenic, some of these species are able to cause quality issues such as browning in cheese.

Microorganisms used in cultured products

As well as the microorganisms discussed above there is a wide range of bacteria, yeasts and moulds that are used in the production of fermented products such as cheese, yogurt and fermented milk drinks. These microorganisms are normally added as starter organisms prior to incubation at temperatures dependant on the product and the characteristics desired. Table 4.3 on the following page lists some of the starter bacteria that are used in the production of cheese and gives an indication of their function. Starters are selected according to the variety of cheese and may be thermophilic cultures for cheeses requiring high scald temperatures or may be gas producers for specific cheese types, such as Emmental.

Mould ripened cheeses will also require the addition of fungal starters such as *Penicillium roqueforti* and *P. camemberti,* with the former normally added into the milk and the latter either into the milk or sprayed on post coagulation.

Table 4.3 Cheese starter organisms

Starter organism	Function
Lactococcus lactis subsp. *lactis*	Development of Acidity
Lactococcus lactis subsp. *cremoris*	Development of Acidity
Lactococcus lactis subsp. *lactis* biovar. *diacetylactis**	Flavour components
Streptococcus citrovorum	Flavour components
Leuconostoc mesenteroides subsp. *cremoris*	Flavour components
*Streptococcus thermophilus***	High temperature starter
Lactobacillus helveticus	Flavour components
Lactobacillus delbreuckii subsp. *bulgaricus*	High temperature starter
Propionibacterium freundenreichii ssp. *shermanii* †	Flavour components and CO_2 production

* May also be called a citrate positive strain of *Lactococcus lactis* subsp. *lactis*

** This organism has also been known as *Streptococcus salivarius* subsp. *thermophilus*

† Formerly *Proprionibacterium shermanii.* Some sources omit the subspecies.

A more recent development in starter organisms has been the use of probiotic cultures in yogurts and fermented milk drinks. Table 4.4 shows the principal species of bacteria that may be used in the production of such products and their roles. It should be noted that probiotic species need to be present at levels exceeding 10^6 g^{-1} in order to be promoted as probiotic. Additionally, there is a range of strains of these species that are used in production.

Table 4.4 Starters for cultured milk and yoghurt

Starter organism	Function
Lactobacillus delbreuckii subsp. *bulgaricus*	Acidity
Streptococcus thermophilus	Acidity
Lactobacillus acidophilus	Probiotic
Bifidobacterium bifidum	Probiotic

In addition to the products mentioned above, kefir has a very distinctive microflora, consisting of bacteria and yeast species. The organisms grow as kefir grains and have a complex make up of microorganisms and exo-polysaccharides and there may be 10-20 species and strains within the grains. In addition to many of the species already mentioned, kefir grains may contain a number of lactobacilli, including *L. brevis*, *L. caucasis*, *L. casei*, *L.cellobiosis* and streptococci, including *S. filant*, *Enterococcus durans* and *Leuconostoc mesenteroides* subsp. *dextranicum*. The grains also contain a range of yeast species including *Kluyveromyces marxianus* var. *lactis*, *K. marxianus* var. *fragilis* and *Zygosaccharomyces florentinus*. All of these add to the flavour and texture of this distinctive beverage.

The microbiology of milk and dairy products is a complex area and this short section gives only an overview of the range of organisms that may be present.

Further reading

Griffiths, M. W. (ed.) (2010) *Improving the Safety and Quality of Milk*, Woodhead Publishing, Cambridge.

Robinson, R. K. (ed.) (2002) *Dairy Microbiology Handbook: The Microbiology of Milk and Milk Products,* Wiley, New York.

Tamime, A.Y. (ed.) (2005) *Probiotic Dairy Products,* (SDT technical series) Wiley-Blackwell, Oxford.

Tamime, A.Y. (ed.) (2006) *Fermented Milks* (SDT technical series) Wiley-Blackwell, Oxford.

5. Dairy plant hygiene

The dairy industry has long been a leader in ensuring the wholesomeness and safety of its products. This is achieved by:

- The adoption of standardised hygienic practices (Good Manufacturing Practices - GMPs or, as they are increasingly called, Pre-requisites) to establish general levels of clean plant, premises, people and products.
- The application of the hazard analysis critical control point (HACCP) system to manage specific food safety hazards which require real time control.

The Hazard Analysis Critical Control Point (HACCP) system is now used widely in the international dairy-processing industry to minimise, manage or control food safety hazards. Use of a HACCP-based control system is implicit in EC food hygiene legislation.

Hygiene hazards in dairy plant

Hygienic practices in the Dairy Plant are necessary to counter the potential contamination risks arising from a range of biological, chemical and physical hazards. Examples of these are given in Table 5.1.

Table 5.1 Examples of potential dairy plant contamination hazards

Biological	Chemical	Physical
Salmonella spp.	Natural toxins	Glass
Listeria monocytogenes	Metals	Wood
Escherischia coli	Drug residues (antibiotics)	Plastics
Staphylococcus aureus	Cleaning residues	Metal fragments
Bacillus cereus	Pesticide residues	Equipment seals
Campylobacter jejuni	Allergens	Insect parts
Clostridium spp.	Maintenance chemicals	Personal items

Traditionally, the most significant hazards in milk and dairy product processing have been microbiological in nature. The established methodologies for controlling them typically include:

- Chilled storage
- Pasteurisation
- Cleaning and disinfection of equipment
- Measures for avoidance of cross-contamination
- GMPs / Pre-requisites

Examples of dairy plant GMPs / Pre-requisites are set out in the pasteurised milk ordinance programme in the USA (*IDFA HACCP Plant Manual*, see Further Reading). These include eight mandatory pre-requisites:

1. Safety of water that comes into contact with food or food-contact surfaces, including ice.
2. Condition and cleanliness of the food contact surface.
3. Prevention of cross-contamination between food, food packaging material, food contact surfaces and unsanitary objects. This includes contact between raw and processed product.
4. Maintenance of the hand washing and toilet facilities.
5. Protection from adulteration with lubricants, fuel, pesticides, cleaning compounds, sanitising agents, condensate and other chemical, physical or biological compounds.
6. Proper labelling, storage and use of toxic compounds.
7. Control of employee health conditions.
8. Exclusion of pests.

HACCP

HACCP

The use of the HACCP system has become a mature food safety system used widely in the international dairy-processing industry. HACCP is a logical, effective, scientifically based and highly structured system of food safety management designed to assist plant HACCP teams in producing a programme to minimise, manage or control hazards. One of the key advantages of the HACCP concept is to enable a dairy/food-manufacturing company to move away from a philosophy of control based on testing, i.e. testing for failure, to a preventive approach, whereby potential hazards are identified and controlled in the manufacturing environment (i.e. prevention of product failure). Use of a HACCP-based or equivalent control system is implicit in EC food hygiene legislation.

A HACCP plan consists of seven principles that, when applied alongside a good Pre-requisite programme, provide for the safety and wholesomeness of dairy foods.

The seven principles are:

1. Conduct a hazard analysis
2. Determine the critical control points (CCPs)
3. Establish critical limits for CCPs
4. Establish a system to monitor CCPs
5. Establish corrective actions, where CCP limits are not met
6. Establish procedures to verify the system is working
7. Establish documentation

Model HACCP plans for most common dairy products are given in the IDFA HACCP Plant Manual (see Further Reading). By far the most important CCP in dairy product processing is a heat treatment, for instance pasteurisation. This provides for measures to ensure that all raw milk receives a minimum statutory heat treatment, e.g. 71.7°C for 15 seconds, while at the same time ensuring that within the pasteurisation plant there is no risk of pasteurised milk being recontaminated by raw milk. Further details of the pasteurisation process are given in the *Milk Processing* section.

Further reading

Griffiths, M. (ed.) (2010) *Improving the Safety and Quality of Milk*, Volume 1. Woodhead Publishing, Cambridge.

Tamime, A.Y. (ed.) (2009) *Milk Processing and Quality Management* (Society of Dairy Technology Series). Wiley-Blackwell, Oxford.

International Dairy Foods Association (2008) *IDFA HACCP Plant Manual*, IDFA, Washington.

6. Milk processing

Composition of UK cow's milk

An indication of typical composition values for cow's milk in the UK is as follows:

Fat	4.0 %
Protein	3.3 %
Casein	2.6 %
Whey protein	0.7 %
Lactose	4.7 %
Ash	0.7 %
Acids (lactic, citric)	< 0.2 %
Water	87.1 %

Both the quantity and compositional quality of milks will vary considerably between herds and especially between individual animals with further variation attributable to stress, health, nutrition and age.

Raw material quality

Production of high quality milk products is dependent on the efficient handling and conversion of good quality raw milk. The general quality criteria for raw milk hygiene within the EU are summarised in Table 6.1. Many purchasers of raw milk have stricter criteria.

Table 6.1 Summary of EU criteria for raw milk supply (source: EU 2005)

Parameter	Requirement	
Plate count @ 30°C	≤ 100 000 cfu mL^{-1}	Rolling geometric average over 2 months
Somatic cell count	≤ 400 000 mL^{-1}	Rolling geometric average over 3 months
Antibiotic residues	< 0.006 IU mL^{-1}	
On-farm storage	Not immediately cooled ≤ 8°C ≤6°C	Only if processed within 2 hours Daily collection Alternate day collection
Chill chain	≤ 10°C	Temperature on arrival
Storage at dairy	No further cooling ≤ 6°C	If processed within 4 hours Unless technological reason for higher temperature
Plate count @ 30°C immediately before processing	≤ 300 000 cfu mL^{-1}	

Milk quality testing at milk processing factories

Density of milk and milk products

At various times in its handling, milk may be measured by either volume or weight. Since the density of milk may be expressed as the weight in kilogrammes per litre of milk at a given temperature, the density of milks can be of commercial importance. For the purpose of laboratory testing the temperature is normally set at 20°C.

The simplest way to determine the density is to use a special type of hydrometer called a lactometer. The upper part of the lactometer is provided with a scale showing a value which, when added as the second and third decimal to 1.000 kg, indicates the density of the milk, e.g. a reading of 30 corresponds to a density of 1.030 kg L^{-1} at the temperature of measurement.

The total solids of the milk can then be calculated using the formula:

$$\text{Total Solids} = 0.25\ D + 1.22\ F + 0.72$$

where F is the % fat by weight in the milk and D = (1000 x density - 1000). If the temperature of the milk is outside 20 ± 0.2°C then a correction must be made to the density reading.

Alternatively, the approximate density of milk or other milk products (assuming no aeration) may be calculated as follows:

$$\rho_{\text{product}} = \text{sum}\ (\%_{\text{component}} \times \rho_{\text{component}} / 100)$$

The densities of the components are given in Table 6.1 below.

Table 6.1 Densities of food components

Component	Density (kg L^{-1})
Fat	0.93
Protein	1.45
Lactose	1.53
Lactic acid	1.53
Ash	2.80
Water	1.00

The approximate densities (kg L^{-1}) of important milk and dairy products are as follows:

Whole milk	1.032
Skimmed milk	1.035
Cream (40% fat)	0.993

Compositional analysis of milk and milk products

The methods of choice for milk and liquid milk product compositional analysis are now based on infra-red spectroscopy, the sample being preheated and homogenised as it flows into the spectrometer. The simpler method employs a series of fixed filters to generate the beams that are shone through a narrow path width, e.g. 60 µm. The absorbances at the different fixed wavelengths are used to calculate the probable composition of the sample, based on calibrations using samples that have been analysed by reference methods. The widespread availability of powerful desktop computers has now enabled Fourier transform infra red (FTIR) spectroscopy to replace filter methods in the larger laboratories and this technology is now being applied to machines for medium and small dairies. The basic machines can all provide measurement of fat, protein and lactose/carbohydrate while the more sophisticated FTIR machines have the potential to provide far more information, e.g. casein and urea contents, plus programmes that can assess the likelihood of a sample being adulterated.

Where only the fat content of milk is needed then a turbidimetric method might still be used. The more labour intensive "Gerber" wet chemistry method may also be used in small factories.

Near-infra-red reflectance and transmittance techniques also now provide very fast analysis of powder, cheese and butter samples but require initial calibration for that product.

Extraneous water

Large additions of water to milk will be reflected in abnormally low compositional data. The extent of contamination is also reflected in the freezing point depression of the milk as the milk solutes become diluted. Modern cryoscopes have a resolution of 1 m°C and repeatability of 2 m°C. A typical cow's milk should have a freezing point of ≈ minus 520 m°C but will vary slightly from day to day and between individuals. (Some older texts may refer to m°H, the Hortvet scale reflecting a systematic error in the method of measuring freezing point depression a century ago.)

Total bacterial and somatic cell counts

These counts have now been automated, for instance using a differential staining technique allied to a direct microscopic count. Values from a total bacterial count are higher than those from a total plate count at 30°C but can be correlated approximately.

Detection of preservatives and antibiotics in milk

The growth of lactic acid bacteria may be inhibited by the presence in the milk of preservatives (such as boric acid, borax, benzoic acid, salicylic acid, salicylates, formalin, hydrogen peroxide) or antibiotics, e.g. penicillin and aureomycin. Limits on antibiotics are included in EC Regulation 2377/1990. In order to find out which of the above-mentioned substances is present, it is necessary to test for each of them – which is both costly and time-consuming. However, tests for rapid determination of antibiotics, especially penicillin, in milk have been developed. One of these is the dutch Delvotest® SP-NT, where a special substrate containing *Bacillus stearothermophilus* var. *calidolactis*, a thermophilic organism that is highly sensitive to penicillin and to some extent also to other antibiotics, is inoculated with the suspected milk. After incubation at 64 ± 0.5°C for 3 hours in the absence of antibiotic, the quantity of acid produced will be sufficient to change the colour in the bromocresol purple pH indicator from purple to yellow. This method determines the penicillin concentration (or equivalent) down to 0.06 IU mL^{-1}.

Rapid detection of slow-ripening milk can be achieved by a comparison of the acidification process in the suspected sample with that in a sample of mixed milk. Both samples are heat-treated at 90-95°C for ≈ 15 minutes, cooled to ≈ 25°C, and mixed with 2% starter. After 6-8 hours there will be a distinct difference in the titres (or pH) of the two samples if one of them contains antibiotics or other growth-inhibiting substances.

Acidity of milk

Normally, fresh milk is very slightly acid with a pH of 6.7 ± 0.1. The pH value is a measure of the hydrogen ion activity, where a value of 7.0 indicates neutrality. A pH value ≤ 6.5 is indicative of souring.

Historically, the acidity of milk has been determined by titration of a sample with sodium hydroxide solution in the presence of a phenolphthalein indicator (end point ≈ pH 8.3). This 'titratable acidity' is a measure of the buffering capacity of the sample and includes the contribution of milk proteins and anions such as phosphate and citrate as well as that of the lactic acid formed by fermentation of lactose.

Different methods (all using phenolphthalein indicators but in differing concentrations) have led to a number of ways of expressing titratable acidity. The most common, the Titratable Acidity (TA), is obtained by titrating a 10 mL sample with 0.111 M NaOH solution and dividing the titre by 10 to give a % lactic acid equivalent.

Standardisation of milk

In many countries, milk sold for consumption must contain a legally fixed fat percentage, although slight variations are usually allowed.
In the UK, for example, heat-treated milks may be:

Unstandardised	≥ 3.5% (as from the cow)
Standardised	≥ 3.5% or as clearly defined on the pack
Semi-skimmed	1.5 – 1.8%
Skimmed	≤ 0.5%, typically 0.1 – 0.3%.

In order to comply with these regulations, it is necessary to standardise the fat content of the milk or cream. This can be done in various ways depending on the stage at which standardisation is carried out.

Standardisation before or during heat treatment is to be preferred as the danger of subsequent contamination is thereby reduced. Standardisation will normally take place automatically in-line during the separating and pasteurising process. It may, however, be done manually as a batch process, using a mass balance equation, standardisation tables or using a graphical approach known as the Pearson's Square technique.

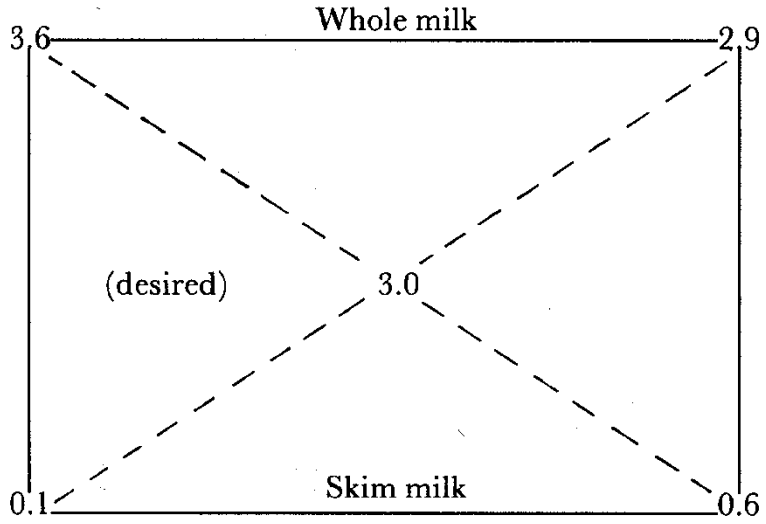
Mass balance
This method is particularly suitable if using a spreadsheet. The equation may be written as:

$$(W_{cream} \times F_{cream}) + (W_{milk} \times F_{milk}) = W_{standardised\ cream} \times F_{standardised\ cream}$$

Where W is the weight and F the fat content of the respective components. Volume can be substituted for weight but, ideally, a correction should be made for the differing densities.

Pearson's Square technique
First draw a square and write the desired fat percentage in the standardized product at its centre and write the fat percentage of the materials to be mixed on the upper and lower left-hand corners. Subtract diagonally across the square the smaller from the larger figure and place the remainders on the diagonally opposite corners. The figures on the right-hand corners indicate the ratio in which the materials should be mixed to obtain the desired fat percentage.
The value on the top right-hand corner relates to the material on the top left-hand corner and the figure on the bottom right relates to the material at the bottom left corner.

Example 1



In this example, the fat content of whole milk is to be reduced to 3.0%, using skim milk produced from some of the whole milk. Using Pearson's Square, it can be seen that for every 2.9 litres of whole milk, 0.6 litres of skim milk must be added.

Pasteurisation

"Pasteurisation is a process applied to a product with the aim of avoiding public health hazards arising from pathogenic micro-organisms associated with milk by heat treatment which is consistent with minimal chemical, physical and organoleptic changes in the product."
(21st session of the IDF Milk Committee, Rome, June 1986)

While the death of pathogens is critical for the safety of the pasteurisation process, the concurrent death of vegetative spoilage organisms can provide an extension to shelf life (though most spores will survive). This benefit is dependent on the process hygiene and the temperature throughout the chill chain.

Mycobacterium tuberculosis was originally considered the most heat resistant pathogen associated with milk and in some areas *Coxiella burnettii* is also a significant risk. More recently there has been concern over the possible survival of *Listeria monocytogenes* and of *Mycobacterium avium* subspecies *paratuberculosis* (MAP).

Within the EU, pasteurisation conditions are laid down in animal products regulations. For milk the minimum temperature / time combinations are 63°C for 30 minutes or 72°C for 15 seconds. Concerns regarding MAP have resulted in many dairies using a 25 s hold.

More severe conditions are often used for milk products, where the increased solute concentration (reduced water activity – a_w) can aid the survival of bacteria. For ice cream mixes, suitable minimum pasteurisation conditions for batch processing are 66°C / 30 minutes or 72°C / 10 minutes, with 80°C / 15 seconds for HTST processes. In each case, rapid cooling to < 10°C is essential and storage temperatures preferably should be < 4°C.

Comparison of the lethality of pasteurisation processes may employ a pasteurisation index, the most appropriate unit for milk being P*, the integral of the lethality of the time-temperature profile of a process using a hold of 15 seconds at 72°C as equivalent to one unit, sufficient to destroy vegetative pathogens in milk. A z value of 8°C is assumed. For safety, a process must have a P* of at least unity (IDF 1986).

Biochemical considerations

Though in-plant monitoring of the process can ensure compliance with the minimum temperature requirement, checks on product must rely on indirect methods. Milk contains a wide range of proteins, including enzymes that are affected by heat to varying degrees. In particular, the enzyme alkaline phosphatase has inactivation characteristics requiring slightly more severe conditions than those associated with the destruction of *M. tuberculosis* and has a relatively high activity in raw milk. Of the more heat-resistant enzymes, lactoperoxidase has been selected as an indicator of excessively severe pasteurisation conditions (above ≈ 80°C / 15 s). Thermal degradation of lactose gives rise to lactulose and denaturation of the β-lactoglobulin fraction of the whey proteins can also be used as an indicator of the severity of heat treatment – see Table 6.2 below.

Table 6.2 Current EU and other/potential indicative standards

	Pasteurisation	High temperature pasteurisation	UHT	In-container sterilisation
Alkaline phosphatase*	-	-	-	-
Lactoperoxidase	+ve	-	-	-
Turbidity	+ve	+ve	±	-
Lactulose (mgL^{-1})	Not detected	< 50	> 100	> 600
β -lactoglobulin (mgL^{-1})	> 2600	≥ 2000	> 50	< 50

- Current EU standard

Phosphatase test

The phosphatase test is used to monitor the effectiveness of high-temperature-short-time (HTST) and batch pasteurisation processes for milk. The original methods monitored the release of either p-nitrophenol or phenol from their respective phosphate esters following incubation at 38 – 40°C for 1 or 2 hours. Release of the yellow p-nitrophenol could be monitored directly while phenol had to be converted into a coloured derivative.

These methods have been largely superseded by faster and more sensitive instrumental methods, reducing test times to a few minutes. The Fluorophos® method uses fluorometric assay to monitor residual alkaline phosphatase (ALP) activity with sensitivity equivalent to contamination by 0.003% raw milk, in 3 minutes. An alternative Charm® PasLite method uses chemiluminescence.

Process design

The mean residence time (T_{av}) in the holding tube can be calculated, using consistent units, as follows:

$$T_{av} = \frac{\text{length of tube (m) x area of cross-section (m}^2\text{)}}{\text{flow rate (m}^3\ \text{s}^{-1}\text{)}}$$

The microbiological safety of the process depends upon the minimum residence time (T_{min}) of a particle passing through the holding tube. If the flow is fully turbulent (Reynolds number > 4000) then:

$$T_{min} = 0.83\ T_{av}$$

However, if the product flow is streamline (Reynolds number ≤ 2300) then the relationship changes to:

$$T_{min} = 0.5\ T_{av}$$

This has a major effect on the lethality of a process, for instance a holding tube with a mean hold of 18 s is sufficient to provide a minimum hold of 15 s under turbulent flow conditions but will only give a hold of 9 s under streamline flow conditions.

Safety in operation

In order to minimise the risk of failure in the pasteurisation process, the system should have an automatic control systems for maintaining:

- Pasteurisation temperature – Temperature recorder and flow diversion valve at the outlet of the holding tube for diverting the flow back to the balance tank in case the pasteurisation temperature falls below the legal/set requirement.
- Holding time at pasteurisation temperature – A constant rate pump and/or a capacity control system, which activates the flow diversion valve in case the capacity exceeds the maximum for which the holding tube is designed.
- Pressure differential control – The system will activate the flow diversion valve if the pressure on the raw-milk side of the regenerator exceeds a set value below the pressure on the pasteurised-milk side, thus preventing possible leakage of raw milk into the pasteurised milk.

Process economics

Economic considerations are also important in milk pasteurisation. Large quantities of milk are pasteurised each day and potentially massive amounts of energy could be needed, both for heating and cooling. This can be minimised by regeneration, where the hot pasteurised product is used to preheat the incoming raw milk. For instance, where raw milk is preheated by regeneration from 5°C to 63°C then pasteurised at 72°C, the regeneration efficiency is: (63 - 5) / (72 – 5) x 100 = 86.5%. In modern high-capacity pasteurisers for liquid milk the regeneration efficiency can exceed 98%. However, in cheesemaking the requirement for pasteurised milk at ≈ 30°C will limit regeneration efficiency to ≈ 63%.

Microfiltration

Microfiltration has been used to reduce the general microbiological load, for instance as a pre-treatment of the skim milk fraction of raw milk to be used in the preparation of raw milk cheeses. It has also been used to remove spores that would otherwise survive pasteurisation or require more severe UHT/sterilisation processes. For further details please refer to the *Membranes* section.

High temperature pasteurisation

Heat treatments above 80°C for 15 s can inactivate the natural biostatic and biocidal activity of milk, e.g. the lactoperoxidase system, so that heat treatments just above those defined for pasteurisation may not improve the shelf life of the milk except under very carefully controlled refrigeration. Cooked flavours may be noted when the milk is compared to correctly pasteurised milk. The heating of milk and other food products to high temperatures results in a range of complex chemical reactions, including the Maillard reactions causing changes in colour (browning) and development of cooked flavours, plus the formation of sediments from protein denaturation and mineral interaction. These

unwanted reactions are largely avoided through heat treatment at a higher temperature for a very much shorter time.

More severe heat treatments can have shelf life benefits and are referred to as extended-shelf-life (ESL) processes as distinct from UHT and sterilised milk processes, though the term ESL may also be applied to some non-thermal processes.

Extended shelf-life (ESL) processes

In many parts of the world the production of fresh milk presents a problem in regard to keeping quality. This is due to inadequate cold chains, poor raw material and/or insufficient process and filling technology. Until recently, the only solution has been to produce UHT milk with a shelf life of 3 - 6 months at ambient temperature.

The term ESL is being applied more and more frequently. There is no single general definition of ESL. Basically, what it means is the capability to extend the shelf life of a product beyond its traditional well-known and generally accepted shelf life without causing any significant degradation in product quality. A typical temperature/time combination for high-temperature heat treatment of ESL milk is 125 - 130°C for 2 - 4 seconds. This is also known in the USA as 'ultrapasteurization'.

APV Invensys has during the last years developed a patented process where the temperature may be raised to as high as 140°C, but only for fractions of a second. This and similar processes reduce the gap between ESL and UHT processes. Table 6.3 compares the potential shelf life achievable by these and other processes.

Table 6.3 Potential shelf life of heat-treated milks (source: APV Invensys)

Process	Log reduction, psychrotrophic aerobic spores	Shelf-life ≤ 4°C storage (days)	Shelf life ≤ 10°C storage (days)
Pasteurisation	0	10	1-2
+ Centrifugation	1	14	4-5
+ Microfiltration	2	30	6-7
ESL heat treatment	8	> 45	≤ 45**
UHT	8*	180	180 ***

* Thermophilic spores with greater heat tolerance

** Depending on filling system

*** Same shelf life at 25°C

Ultra-high-temperature (UHT)

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). In practice, the products are checked for commercial sterility by incubating at 55°C for 7 days or at 30°C for 15 days, then testing for bacterial growth (EU, 2005).

This calls for application of heat to the product and a chemical sterilant or other treatment that renders the equipment, final packaging containers and product free of viable micro-organisms able to reproduce in food under normal conditions of storage and distribution. In addition it is necessary to inactivate toxins and enzymes present and to limit chemical and physical changes in the product. In very general terms it is useful to have in mind that an increase in temperature of 10°C increases the sterilising effect 10-fold whereas the chemical effect only increases approximately 3-fold, thus permitting a tenfold reduction in the holding time but with more than a three-fold reduction in cooked flavour. The relationships between the effects of severe heat treatment on the microbiology and chemical constituents are illustrated in Figure 6.1. These changes may be treated quantitatively in terms of B* and C* units where:

B* is the integral of the lethality of the time-temperature profile of the process using a hold of 10.1 s at 135°C as equivalent to one unit, sufficient to give commercial sterility assuming a Z value of 10.5°C.

C* describes the chemical damage based on 3% destruction of thiamin, where one unit is based on 35 s at 135°C and assuming a Z value of 31.4°C.

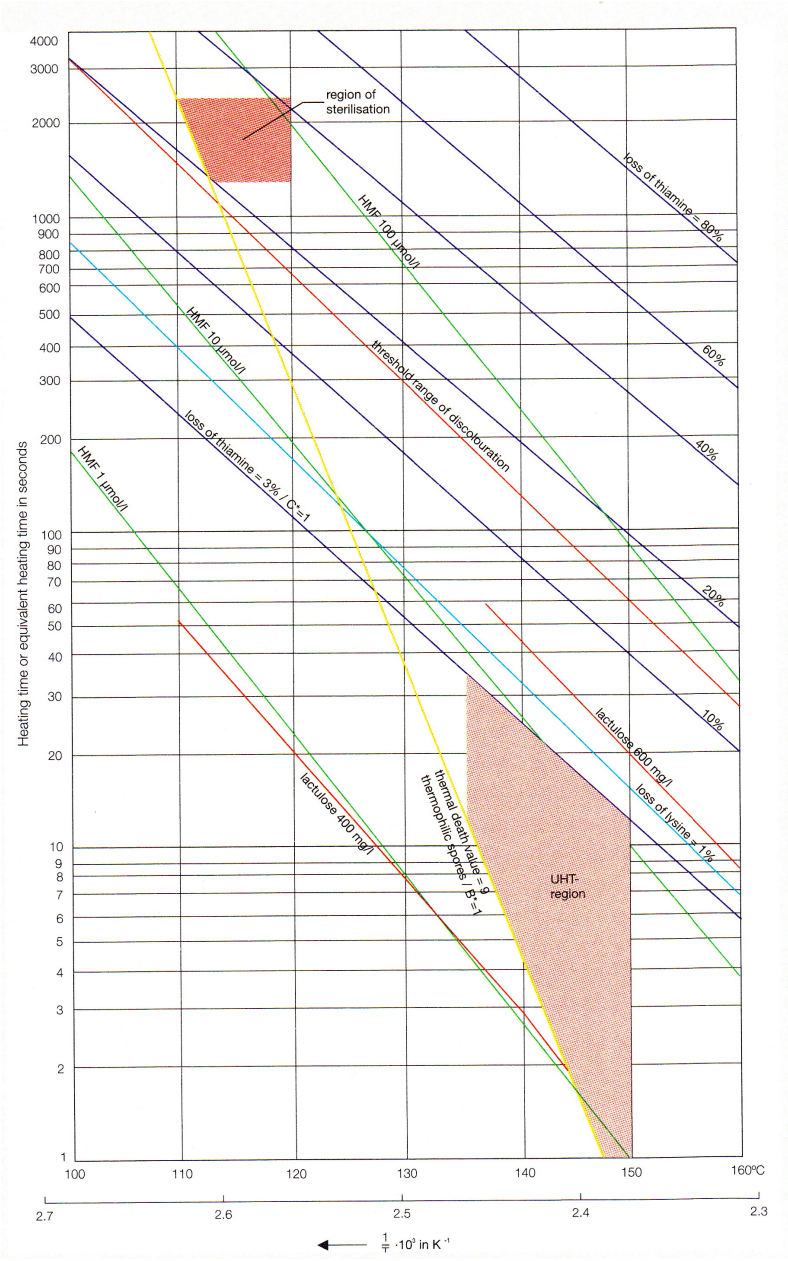


Fig.6.1. An illustration of the effects of temperature and time on the microbiology and on some constituents of milk (Courtesy of SPX)

With high temperature processing small differences in time can thus have large effects on both the microflora and the chemical quality of the milk. Increasing the thermal efficiency of processes tends to increase the time at higher temperatures, with consequent greater chemical damage. Temperature-time profiles of commercial processes are illustrated in Figure 6.2.

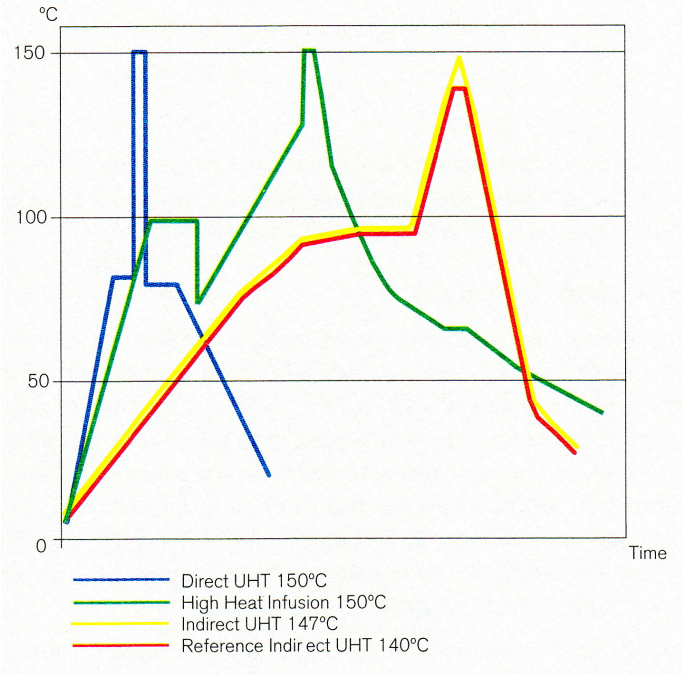


Fig. 6.2. Temperature-time plots for UHT processes (Courtesy of SPX)

It is important to seek the optimum time/temperature combination that provides a sufficient biocidal effect on spores but, at the same time, limits the heat damage in order to comply with market requirements for the final product.

UHT processing of milk combined with aseptic packaging was introduced to produce a shelf-stable product with minimal chemical damage when compared to in-container sterilised milk. Aseptic packaging systems commonly employ a form-fill-seal approach with sterilisation of the packaging immediately prior to forming. Other systems may employ sterilisation of pre-formed packaging immediately prior to filling. All systems operate in an aseptic environment, with hydrogen peroxide plus heat as the standard sterilising agent.

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. In this situation, UHT milk may need to be stable over a long period of time.

Sterilisation

This term implies in-container sterilisation when used with milk. Milk may be sterilised in either plastic or glass bottles. Typically the milk is standardised, homogenised, high-temperature pasteurised and filled hot into the bottles before subjecting to either batch or continuous heat treatment in a retort at temperatures of 115 – 120°C for ≥ 30 minutes. The resulting product has a light brown colour and characteristic cooked flavour.

Further reading

BS (1959) *BS 734-2:1959 Density Hydrometers for use in Milk – Part 2: Methods*. British Standards Institution, London

Burton, H. (1988) *UHT Processing of Milk and Milk Products*. Elsevier Applied Science, London.

Deeth H.C. & Lewis M.J. (2017) *High temperature processing of milk and milk products.* Wiley-Blackwell, Oxford.

EU (2005) Commission Regulation (EC) No. 2074/2005 of 5 December 2005 laying down implementing measures for certain products under regulation (EC) No. 853/2004 of the European Parliament and of the Council and for the organisation of official controls under Regulation (EC) No. 854/2004 of the European Parliament and of the Council and Regulation (EC) No. 882/2004 of the European Parliament and of the Council, derogating from Regulation (EC) No. 852/2004 of the European Parliament and of the Council and amending Regulations (EC) No. 853/2004 and 854/2004. *Official Journal of the European Commission*, **L338**, 27-58.

Food Standards Agency (2009) *Information and guidance on the testing of Milk for antibiotic residues.*Food Standards Agency, London.

Hoffman, W. (2002) Cream. In *Encyclopaedia of Dairy Sciences* (Eds. H. Roginski, P.F. Fox & J.W. Fuquay) pp 545–551, Academic Press, London

IDF (1986) *Monograph on pasteurised milk*. Document No. **200**, International Dairy Federation, Brussels.

Lewis, M.J. & Heppell, N. (2000) *Continuous Thermal Processing of Foods: Pasteurization and UHT Sterilization*. Aspen Publishers, Gaithersburg.

Mullan, W.M.A. (2006). *Pearson square or rectangle*. [On-line]. Available from: https://www.dairyscience.info/calculators-models/133-pearson.html [28 March, 2018]

Tamime, A.Y. (ed.) (2009) *Dairy Fats and Related Products*. Wiley-Blackwell, Oxford.

Tamime, A.Y. (ed.) (2009) *Milk Processing and Quality Management*. Wiley-Blackwell, Oxford.

7. Cream

Cream is generally prized for its consistency and for its rich taste. Fears about excessive fat in the diet contributed to a decline in cream consumption at the end of the 20th century but the overall cream market has since stabilised.

Up till the late 19th century, cream was separated from milk by leaving the raw milk in shallow bowls to stand overnight. The cream rose to the surface and was scooped off the following morning. This was not a hygienic process and the cream would often be sour. The invention of continuous separation and adoption of pasteurisation enabled more hygienic and larger-scale processing, moving from farmhouses to purpose-built creameries.

Separation

Most cream separation is now a byproduct of the large-scale production of standardised milks, though some smaller plants may still be separating cream as the primary product and using the skim milk for other products. The most efficient temperature for separation is ≈ 63°C. Temperatures in excess of 40°C are needed to ensure that all the milk fat is liquid so that the milk fat globules are elastic and less easily damaged. Separating at lower temperatures can result in damage to the fat globules, causing release of fat and making the cream both less stable and more prone to lipolysis. Occasionally milk may be separated cold and in this case the fat content of the cream is kept low to minimise damage to the fat globules

There are several designs of milk separator, the common factor being the use of a conical plate stack within which the milk fat globules move inwards by flotation and become concentrated to form the cream, the slower the cream flow then the higher the fat content. Modern high capacity separators have a split-bowl design, enabling periodic de-sludging during a run and permitting cleaning-in-place. These separators can give skim milk with less than 0.05% fat.

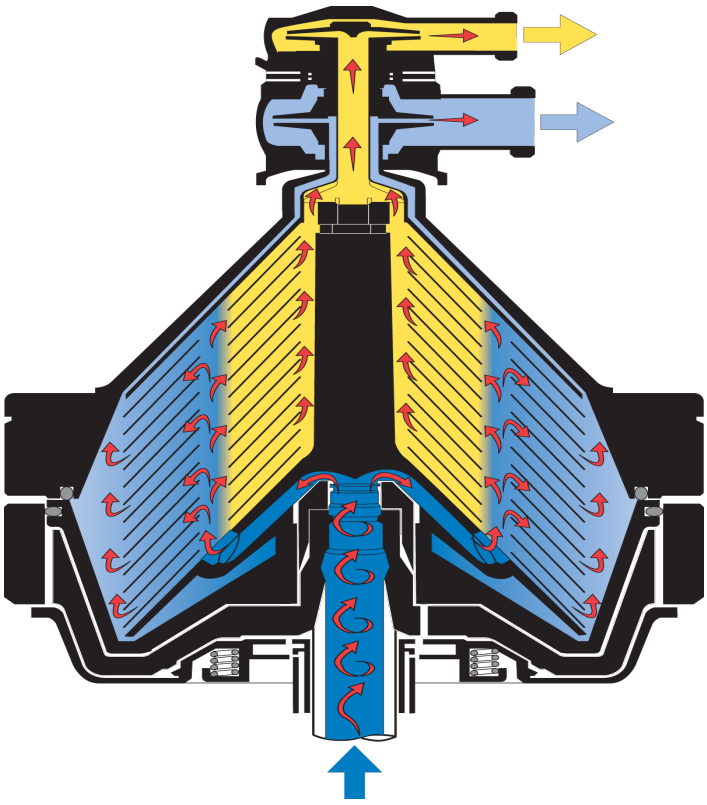


Fig. 7.1 Section through a cream separator with bottom feed, illustrating the fat concentration to form cream (coloured yellow) and skim milk (light blue). (Courtesy of Tetra Pak)

Standardisation of cream

Modern large-scale milk separation plants are capable of producing standardised cream that simply needs to be pasteurised and subjected to any further processing.

In the UK the designated minimum fat levels are:

Half cream	12% fat
Cream	18%
Sterilised cream	24%
Whipping cream	35%
Double cream	48%
Clotted cream	55%.

Different standards are applied in other countries.

With smaller-scale production then cream is often produced at the highest fat content that may be needed then batches are standardised to the desired fat content prior to pasteurisation. As with milk standardisation, the quantities can be calculated using a mass balance equation or Person's Square.

Mass balance

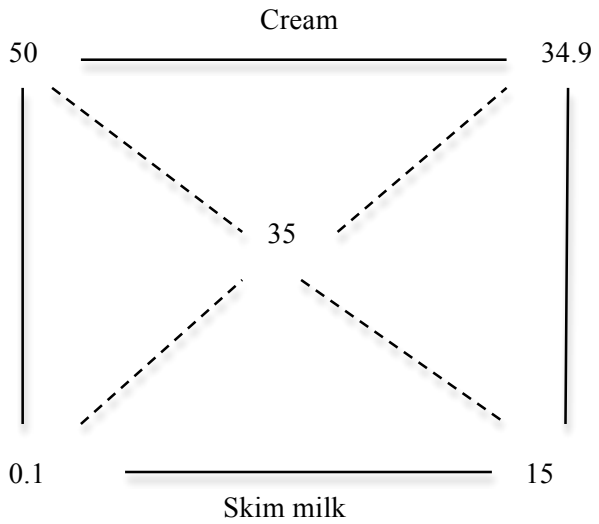
This method is particularly suitable if using a spreadsheet. The equation may be written as

$$W_{\text{standardised cream}} = \frac{(W_{\text{cream}} \times F_{\text{cream}}) + (W_{\text{milk}} \times F_{\text{milk}})}{F_{\text{standardised cream}}}$$

where W is the weight and F the fat content of the respective components. Volume can be substituted for weight but, ideally, a correction should be made for the differing densities.

Pearson's Square technique

This technique may also be applied to batch cream standardisation and was widely used in small dairies. For example, to produce a 35% fat cream by blending 200 kg of 50% fat cream with skim milk containing 0.1% fat:



If 34.9 parts of cream require 15 parts of skim milk, 200 parts of cream require 'x' parts of skim milk.

Weight of skim milk needed = x = (200 × 15)/34.9 = 85.96 kg

Homogenisation

Homogenisation is applied to many cream products, both to enhance viscosity and to reduce flotation of the fat globules. This process seeks to reduce the size of fat globules and, like centrifugal separation, is an application of Stokes's Law:

$$v = \frac{D^2 g (\rho_f - \rho_p)}{18\mu}$$

where:

v = rate of flotation (or sedimentation if the particle is more dense than the fluid)
D = diameter of the particle (m)
g = acceleration due to gravity (m s^{-2})
ρ_f = density of the fluid (kg m^{-3})
ρ_p = density of the particle (kg m^{-3})
μ = dynamic viscosity (kg m^{-1} s^{-1})

As a general rule, it is safer to carry out the homogenisation upstream of heat treatment.

Half and single creams

The fat globules account for less than 20% of the volume of these products so movement of fat globules is unhindered, giving both low viscosities and allowing flotation to occur. Homogenisation reduces the mean fat globule size, reducing the rate of flotation. Reduction in mean fat globule size increases the surface area of the fat globules, thus increasing interactions between fat globules and increasing viscosity.

In most cases, homogenisation is carried out at temperatures above the melting range of milk fat, typically about 50°C preferred. Homogenising below 40°C leads to free fat and a poor, unstable, emulsion with a greasy taste. Generally there is a non-linear increase in viscosity with homogenisation pressure and an increasing adsorption of casein onto the new fat globule membrane as surface area increases. This casein adsorption changes the properties of the fat globule membrane, making it more susceptible to coagulation at reduced pH, an important limitation if the cream is to be used with hot coffee or poured over acidic fruits. If the cream is to be used for pouring over fruit then homogenisation at up to 17 MPa with minimal second stage may be suitable but for a coffee cream then lower pressures may be desirable, e.g. 13 MPa including a 3 MPa second stage.

Sterilised cream

In-container sterilised cream was important up to the mid-20th century but now has a minimal market share, having been rsuperceeded by pasteurised and UHT-treated products.

Whipping creams

These products are best not homogenised as the whipping properties are likely to be compromised by homogenisation. However, if a stabilised whipping cream is being produced for use in a bakery or similar large-scale application then the cream can be passed through the homogeniser with minimal pressure applied, just sufficient to ensure dispersal of the stabiliser. Stabilisers are usually dry-blended with sugar before dispersal in the cream.

Double cream

With fat globules taking up 50% of the volume in double cream, there is little need for homogenisation to improve stability and it has been argued that flavour can be adversely affected. Where a thicker double cream is desired then light homogenisation at up to 3.5 MPa /43–50°C may be used.

Clotted cream

There is no need for homogenisation of cream in the preparation of clotted cream though, sometimes, homogenised double cream may be included in the recipe.

Heat treatment

In theory there is no need to use a heat treatment for creams that is more severe than for milk, in order to protect public health. However, in practice it is common to use more severe heat treatments, for instance the IDF recommends 75°C /15 s for creams of 18% fat and 80°C / 15 s for 35% fat contents and above. Since cream pasteurisers are frequently used with creams of different fat contents and levels of homogenisation, such equipment has to cope with a wide range of viscosities. When the viscosity of a cream increases then the Reynolds number in the holding tube decreases and there is a risk of the flow properties changing from turbulent to streamlined, resulting in a lowering of the minimum residence time despite the average residence time being maintained. Such a change would result in the lethality of the process being reduced, hence the common practice of raising the holding temperature as compensation. More severe treatments will result in the generation of cooked flavours.

The cooling process for pasteurised cream is more complex than for milk. The higher viscosity of most creams as they pass through the heat exchanger results in greater shear so that rigorously cooled cream is likely to have a lower final viscosity than cream that has been subjected to gentler handling. (This is less important for whipping cream, which may be cooled to 5°C.) In addition, fat crystallisation within the milk fat globules is relatively slow and the milk fat globules will contain supercooled liquid fat that will subsequently crystallise over a period of time after leaving the heat exchanger, releasing latent heat of crystallisation. With double cream it is not unusual to find a 2°C rise in temperature within 90 minutes of the heat treatment.

Thicker creams can be achieved by only cooling to about 20°C then continuing the cooling in a jacketed vessel with very gentle stirring before filling. Extra thick creams may be filled at 15–20°C then immediately transferred to a blast cooler to be cooled under zero shear conditions, usually leading to a set product in the case of double cream. While these methods are very effective in achieving the desired physical properties, excellent hygiene is essential in avoiding post-process contamination problems.

As with milk, the effectiveness of heat treatment of cream from raw milk can be monitored using the ALP test. ALP is associated with the MFGM so the higher concentration of fat globules leads to higher activities and reactivation of the enzyme can occur, particularly if the cream is stored warm after heat treatment. Double-pasteurised and severely heat-treated creams will also give negative results for more heat-resistant enzymes such as lactoperoxidase and γ-glutamyltranspeptidase.

Clotted cream

Manufacture of this traditional cream has followed one of two methodologies, the float and scald processes for heat treatment. The severe and extended heat treatments confer a typical cooked flavour in the cream. Originally the processes would have used raw cream but concerns over possible under-processing of the surface layers have led to the widespread use of pasteurised creams. Good clotted creams will have a fat content well in excess of the minimum 55%, often ≥ 60%.

The float process is an adaptation of the traditional farmhouse method, preferably using a water-jacketed pan. In the larger-scale method, shallow jacketed vessels, e.g. 1800 x 750 x 125 mm deep, are part-filled with 100 litres of skim milk then 36 litres of double cream floated on top. The vessel is then heated by steam or by circulation of hot water till a crust is formed. Chilled water or brine is then circulated through the jacket to cool the cooked cream, continuing the cooling for about 12 hours or overnight till the cream layer has set and the cream is at 4–7°C. The entire processing room should be refrigerated during this phase. The set cream is then gently removed using a shallow scoop and placed into containers, retaining as much as possible of the crust. The residual milk should be collected and reseparated, the recovered cream being used for buttermaking or other products.

The scald process differs in just using a thin layer of cream, 13–25 mm deep, in a shallow tray. These trays may be 500–700 mm long, 80–600 mm wide and 75 mm deep and there is also an option to use small heat-resistant containers, e.g. aluminium or polypropylene, in the trays. The fat content of the cream will vary inversely with depth of fill and expected rate of evaporation. Heat treatment takes place in a tunnel oven, floating the trays on hot water at 90–100°C to give a final temperature of 77–85°C in 45–70 minutes. The hot cream is then typically transferred to a similar cooling tunnel where the trays are floated on chilled water and/or the trays dried and placed into a cold

store to cool and set. As with the float process, air quality is critical in avoiding post-process contamination and consequent spoilage.

Hot water heating is not essential for the scald process and many variants have been used, including the use of fan-assisted and microwave ovens. Whatever the heating method, the key requirement is to minimise flow within the cream during heating and particularly during cooling so that there is the maximum opportunity for the cream to achieve a gel-like consistency with retention of the characteristic crust.

UHT creams

The serum phase of cream is the same as for milk and there are no special problems in heat treatment provided that the cream is sourced hygienically from good quality milk. For UHT creams a heat treatment at 140°C for 2 seconds may be used. Downstream homogenisation is commonly used, eg. 3.5–4.5 MPa at 65–78°C. Except for some whipping creams, additives are not generally needed though the resistance of coffee creams to feathering may be improved by adding a chelating agent such as trisodiun citrate at about 0.15% where permitted by local legislation. The functionality of whipping creams may suffer as a result of the severe processing and be improved by addition of caseinate or whole milk protein, emulsifiers and/or stabilisers. Sweetener addition also aids dispersion of stabiliser. Aerosol creams employ nitrous oxide as the propellant and typically will require emulsifier addition, giving unstable foams with very high overruns of 400–500%.

Cultured creams

Heat treatment of creams for culturing is more severe than for sweet creams, e.g. 85°C / 30 minutes, 95°C / 15 s or 120-130°C flash. The severe heat treatment causes denaturation of whey proteins, creating micro-aerobic conditions plus casein-whey protein complexes that improve water-binding and gel formation on acidification. Homogenisation is better carried out downstream of the heat treatment, with further cooling to 20–24°C then inoculation with a mixed-strain mesophilic starter including citrate fermenters (*see section on cultured cream for butter*).

Storage

Pasteurised cream has a similar shelf life to milk and must be kept cold, preferably at or below 3°C though avoiding freezing, which would destabilise the emulsion.

Correct storage is also critically important for the functionality of whipping cream. β-casein diffuses from the casein micelle into the serum phase at low temperature and this protein plays a major part in the initial stabilisation of the air cells during aeration. Further whipping leads to partial displacement of protein by fat globules at the air-serum interface and the build-up of a three-dimensional matrix of partially coalesced fat globules. At higher temperatures not only is there less β-casein but a higher proportion of liquid fat in the globules, leading to a less stable foam with a propensity for buttering (*see next section on Butter*).

The storage stability and firmness of whipped creams increase with fat content. It is common for the fat content of whipping cream to be increased in late spring and summer, partly to compensate for possible seasonal effects on the protein and fatty acids but also to allow for the challenges from higher ambient temperatures to the chill chain.

Further reading

Deeth H.C. & Lewis M.J. (2017) *High temperature processing of milk and milk products.* Wiley-Blackwell, Oxford.

Smiddy M.A., Kelly A.L. and Huppurtz T. (2009) Cream and related products. In *Dairy Fats and Related Products*. Edited by A.Y. Tamime, Wiley-Blackwell, Oxford.

Tetra Pak *Dairy Processing Handbook*. Tetra Pak Processing Systems, Lund.

Wilbey R.A. & Young P. (1989) Scalded and Clotted Cream, *Cream Processing Manual*, 2nd edition, Ed J. Rothwell, Society of Dairy Technology, Huntingdon.

8. Butter

Butter is the most common form of concentrated milk fat. It is valued for its delicate flavour, its melting characteristic in the mouth, and it's keeping quality. Typically it contains some 80-83% milk fat, 15-16% moisture, less than 2% MSNF plus 1.5-1.7% salt in the salted varieties. In most countries the legal standards are a minimum of 80% milk fat and a maximum of 16% moisture.

Background science

The manufacture of butter is possible as a result of the unique chemistry and physics of the fat system in milk. From a chemical perspective, milk fat is predominantly (>98%) triglycerides – mostly dispersed in milk in the form of fat globules (diameter 0.1 to 10 µm) stabilised by the MFGM (see section on *Milk fat*). The triglycerides in milk fat vary in their chain length and degree of unsaturation, giving a wide range of melting points. For example at 40°C all of the milk fat is liquid while at 5°C less than 50% of the fat is liquid, the proportion varying with season and particularly diet.

The other physical property of milk fat important for buttermaking is the ability of the fat globules in cream (>36% fat) to aggregate when whipped in air (e.g. as in whipped cream). These natural chemical and physical properties of the milk fat system determine the first two of three distinct sets of physical changes that take place during the butter making process, as summarized in Table 8.1 below.

Table 8.1 Summary of changes taking place during buttermaking

Key Steps	Physical Changes
Ageing of the cream After pasteurisation, the cream (40% fat) is cooled to 4-5°C and held for several hours (typically 8-15 h).	This allows the higher melting fraction of the milk fat to crystallise and become solid. The time and temperature of the ageing process depends on the relative hardness of the milk fat, which varies mainly according to feed.
Churning the cream Where the aged cream is subjected to a high level of shear and aeration.	Fat globules are most easily disrupted when approximately half of the fat is solid, allowing liquid free fat to escape from the globules. This allows the globules to collect in clusters 'stuck together' by free fat. When these clusters become large enough they appear as small clumps, or butter grains. The remaining liquid is called buttermilk.
Treatment of the butter grains Butter grains separated from buttermilk Butter grains physically worked Salt addition, moisture content adjusted De-aeration	 To reduce the moisture content of the butter To reduce the size of the moisture droplets in the butter (ideally to <10 µm to minimise microbial growth) Salt is added for flavour and as a preservative (lowers a_w), moisture to optimise yield. To remove and standardise the residual air.

Manufacturing process

The key steps in the butter making process are set out in Table 8.2 on the following page using the continuous production of sweet cream salted butter as an example (the most popular type of butter in the UK).

Table 8.2 Summary of process for sweet cream salted butter

Unit Operation	Purpose
Pasteurisation of cream (40% fat) at 85-95°C for 10-30 seconds (minimum 72°C for 15 s)	Eliminate pathogens & spoilage organisms Inactivate enzymes.
Ageing cream at 4-5°C for 12-15 hours (minimum 4 hours)	Development of extensive network of fat crystals.
Warming cream to churning temperature (7-13°C, typically 9-11°C)	Optimum temperature for the following churning process.
Churning in a high speed rotary beater	Fat globule disruption and coalescence to form butter grains and buttermilk.
Separation of butter grains and buttermilk	Remove liquid buttermilk to recover butter solids.
Working of butter grains through sets of perforated plates	Dispersion of moisture droplets and develop the desired consistency in the butter.
Addition of salt as a 50% slurry	Salted for flavour and as a preservative
Adjustment and distribution of moisture	Moisture introduced to bring butter moisture content close to the 16% legal limit in most countries. Moisture droplets are reduced in size to 5-10 µm to minimise microbial growth.
Final working under vacuum	Standardise and minimise air content to reduce risk of oxidation and by standardising density to minimise giveaway on packaging.

All but the first three of these operations are carried out in a butter making machine. Today these are almost all continuous machines based on the 'Fritz' design. An example of a Fritz butter maker is shown in Fig.8.1.

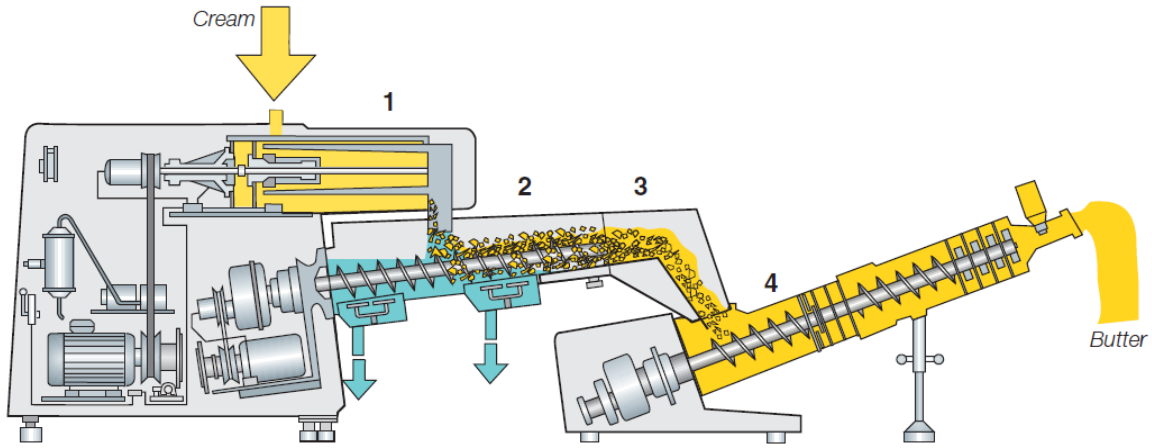


Fig 8.1 Schematic of continuous buttermaker (Courtesy of TetraPak)

In the above figure, aged, pre-warmed cream is pumped to the horizontal churning section (1) where the butter grains are formed. An inclined section then provides for the draining of the buttermilk via a screen, the grains then being compacted in the first working section (2) before dropping through the vacuum section (3) before further compaction and moisture dispersion in the second working section (4).

In the first working section salt is added and the moisture content adjusted. By the end of the second working section, the moisture droplets have been reduced in size to 5-10 µm and the butter is extruded as a ribbon for transfer to the packing station.

Varieties

The manufacturing process outlined above relates to sweet cream butter. Much of European butter is produced as lactic butter, where the cream is traditionally cultured with starter bacteria prior to churning. Nowadays, this is more usually achieved by in-line injection of lactic acid and diacetyl-based flavouring into the butter maker to give the same flavour and acidity characteristics.

Sweet cream butter has a typical pH of 6.7 compared with a full lactic butter at pH 4.5. Both types of butter can be unsalted, slightly salted (0.7 – 1.0% salt) or salted (1.7 – 2.0% salt).

Butter itself has a minimum fat content of 80%, but it is also legal to produce reduced fat butter (60-62% fat) and low fat (or half fat) butter (39-41% fat).

Butter spreadability

The firmness and spreadability of butter is largely dependent on the proportion of the milk fat that is solid at a particular temperature. The solid fat % is itself determined by the chemical composition of the milk fat, i.e. by the proportions of the different fatty acids it contains. After manufacture, butter firmness increases further on storage as some of the fat continues to crystallise and "set".

At some times of the year, e.g. during the winter months in the UK, the firmness of butter is too hard to be spreadable, especially at refrigeration temperature. A number of technologies have been developed to address this, and in particular to reduce the solid fat % in butter:

i. Cream tempering – where the solid fat % can be reduced by tempering the cream at around 20°C for some 2 hours before cooling and churning at the normal temperature (Alnarp process or similar). The tempering period allows some of the fat to recrystallise, giving a lower solid fat %.
ii. Fractionation – where a soft milk fat fraction with a relatively low solid fat % can be produced by cooling milk fat, and separating any solid, crystallized, fat by filtration. The soft fraction can then be blended with standard milk fat to give a lower overall solid fat %. A similar effect can be achieved by using stored, relatively soft summer butter.
iii. Microfixing – where stored butter is first comminuted to break down its structure before reforming it by forcing it through an orifice under pressure. The shearing effect breaks down the fat crystal structures responsible for storage induced "setting".
iv. Protected feed – where oilseed cattle feed is chemically treated to prevent the cow hydrogenating it in the rumen. This reduces the saturated fat content of the milk fat, thereby reducing the milk fat's solid fat %.

Yield issues

During the buttermaking process, some milk fat is lost as processing losses (losses to drain from spillages, cleaning etc) and some is lost into the buttermilk (churning loss). The latter is usually centrifuged in a milk separator to recover most of the fat as cream. With efficient churning, the buttermilk should contain no more than 0.5% fat, with over 99% of the cream fat recovered in the butter.

In addition to process and churning losses, the key yield control measure is maximising the moisture content while keeping within legal limits. With continuous buttermakers, this may be achieved using in-line moisture analysers.

Typically, 1 kg of butter is produced from 20 kg of milk with a fat content of 4.2%.

Further reading

Mortensen, B.K. (2012) *Butter and related products: product characteristics, production technology and quality aspects.* International Dairy Books, Odense.

Walstra, P.F, Wouters, J.T.M. & Geurts, T.J. (2006). *Dairy Science and Technology*, 2nd edition CRC/Taylor & Francis, London publishing,

Wilbey, R.A. (2009) Butter, in *Dairy Fats and Related Products.* Edited by A.Y. Tamime (Society of Dairy Technology Series). Wiley-Blackwell, Oxford.

9. Cheese

Cheese is the concentrated form of milk protein and milk fat produced by the coagulation of milk and the subsequent separation of the curds and whey. Cheese is often an important aspect of a country's culture and the literally hundreds of varieties reflect centuries of regional differences.

Cheese is produced in a wide range of textures and flavours, and is a valuable food protein source with good keeping quality.

Background science

Whereas butter manufacture depends on the chemistry and physics of the fat system of milk, cheese manufacture is based on the unique chemistry and physics of the main protein system in milk, casein.
The cheese making process involves four quite distinct chemical and physical changes:

i. Lactose fermentation – where the lactose in milk is converted by starter-culture bacteria to lactic acid, reducing the pH.
ii. The pH reduction results in progressive loss of calcium from the casein micelles into the serum as soluble calcium.
iii. Coagulum formation – This happens in two stages:
    a. The κ-casein on the surface of the casein micelles in milk is cleaved at the 105-106 linkage by the enzyme chymosin to release a macropeptide (CMP) that is lost into the serum, leaving a relatively hydrophobic residue of para-κ-casein. Unlike κ-casein itself, para-κ-casein is subject to reaction with calcium.
    b. The soluble calcium in the milk promotes the formation of aggregates of para-κ-casein, forming a coagulum or gel. This coagulum is a matrix of casein micelles which entraps the milk fat globules and most of the bacterial microflora within it
iv. Syneresis – Once the coagulum has formed, it naturally contracts as the protein bonds become stronger and whey is expelled. This natural process of whey release (syneresis) can be accelerated by cutting the coagulum into smaller cubes, by raising the temperature and/or by applying pressure (including stirring).
v. Maturation – where various chemical and biochemical changes occur in the protein and fat brought about by the process conditions used and the action of enzymes from the milk itself, the rennet, the starter bacteria and adventitious contaminants from the factory environment.

These are the key processes that are responsible for the flavour and texture of different cheese varieties

Manufacturing process

The key steps in the cheese manufacturing process are set out overleaf in Table 9.1 using Cheddar as the example, as this accounts for 65% of UK cheese production.

Table 9.1 Operations in Cheddar cheese manufacture

Unit Operation	Purpose
Pre-treatment of milk: Standardisation of composition Pasteurisation Additions (optional)	 Control of fat content of final cheese Destruction of pathogens Annatto if cheese is to be coloured, $CaCl_2$ to assist curd formation
Starter culture addition – usually strains of *Lactococcus lactis* subsp. *lactis* & *L. lactis* subsp. *cremoris*. (Sometimes *Streptococcus thermophilus* may also be added.)	Production of lactic acid by bacterial fermentation of lactose Development of flavour and aroma compounds
Rennet addition	Coagulation of milk protein to produce a coagulum, entrapping milk fat and starter organisms
Cutting	Cutting the coagulum into small cubes (typically 6 mm, other varieties 5-30 mm) facilitates whey release (syneresis)
Scalding	Raising temperature accelerates syneresis
Whey drainage	Whey drainage releases bulk of whey from cheese curd
Curd texturisation	Physical handling of curd, e.g. Cheddaring, to develop required texture
Milling	Reducing curd to similar sized pieces to facilitate even salt distribution
Salting	Salt addition slows acid production and aids curd fusion. Salt enhances flavour and acts as a preservative
Pressing/moulding	Pressing to remove residual whey and mould into final shape
Bulk Packing	Vacuum packing for storage
Maturation	Storage at 8-12°C to develop flavour and texture through enzymic breakdown of protein and fat

Figure 9.1 below illustrates these processes for a typical large-scale Cheddar manufacturing process:

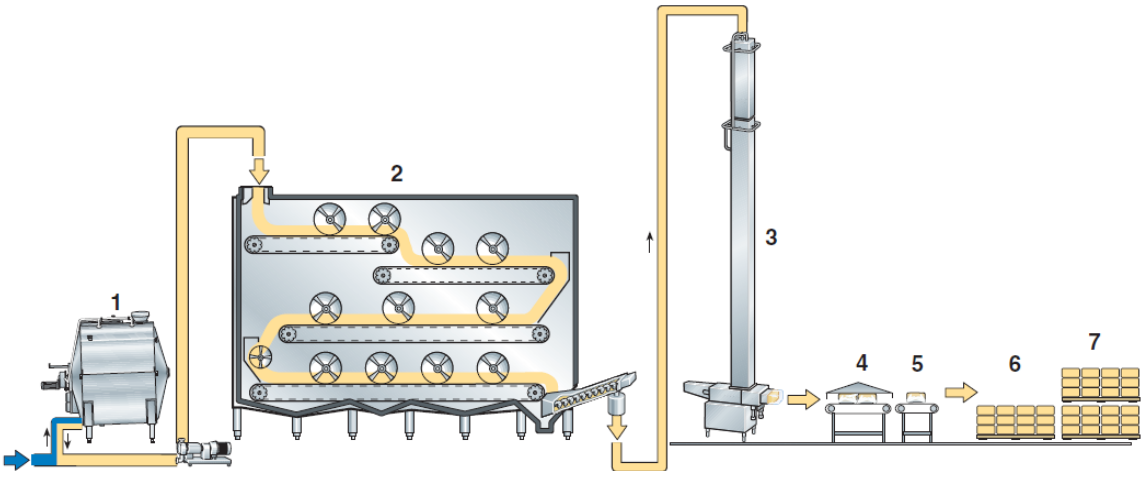


Fig. 9.1 Schematic of large-scale Cheddar manufacturing line (Courtesy of TetraPak)

Pre-treated milk is pumped to the cheese vat (1) where first starter culture and then rennet are added. After around 40 minutes, the coagulum is cut with a series of rotating blades and the cubes of curd then stirred with the whey while the temperature is gradually raised to around 39°C and held at that temperature till the desired acidity/texture has been achieved.

The curds and whey are then pumped to the cheddaring machine (2) where the whey is first drained off via a screen, and the curd falls onto the first of a series of conveyor belts. Curd on a belt can be either stirred or allowed to form into a mat, the latter being usual for Cheddar. At the end of the third belt the mat of curd is chopped up by a mill to reduce the curd size and aid salt absorption. A salting station is incorporated over the fourth belt, where salt is applied to achieve around 1.8% in the finished product.

The salted curd is stirred on the belt then transferred to a blockformer (3) where the curd is pressed under its own weight in partial vacuum, allowing further whey removal. At the base of the blockformer the curd is cut into 20 kg blocks, vacuum packed (4), placed into a strong cardboard box (5), palletised and rapidly cooled (6) before transfer to a maturation store (7).

Varieties and composition

Varieties

Cheese varieties are distinguished in two ways, either ripened, i.e. matured over weeks/months to develop flavour and texture, or unripened (fresh), i.e. ready to eat straight away. Ripened (matured) cheeses are then usually classified on the basis of their texture, which itself is largely determined by the moisture content.

Unripened soft cheeses such as fromage frais and quarg were traditionally made by adding starter and rennet to milk, and then straining the cut curd through a cheese-cloth or cloth bag. This gives a product with between 14 and 25% total solids, depending on the fat content. Modern manufacture of these soft, unripened cheese products involves the use of high-speed centrifugal separators, which separate the curds and whey on the basis of density difference. Soft cheeses such as ricotta are made by heating acidified mixtures of milk and whey to recover whey proteins in the curd.

Matured (aged) cheeses can be classified according to their moisture content and hardness, and as to whether additional moulds or specific bacteria are used in the ripening process, as illustrated in Table 9.2.

Table 9.2 Examples of matured cheese

Variety	Texture	Moisture (typical %)	Mould used
Parmesan	Extra hard	30	None
Cheddar	Hard	37	None
Edam	Semi-hard	44	None
Stilton	Semi-hard	40	*Penicillium roquefortii*
Brie	Soft	52	*Penicillium camemberti*
Mozarella	Soft	50	None

Cheese composition

The classification of cheese varieties shown in Table 8.2 is based on their moisture content. It is now more usual to define cheese characteristics using the following three ratios:

i. Fat in dry matter (FDM) – This is the fat content of the cheese as a percentage of the total solids content. It determines the level of creaminess of the cheese. Cheddar has a typical FDM of 50 to 55%, while Continental varieties have FDM's between 20 and 50%.
ii. Moisture in non-fat substance (MNFS) – This is the moisture of the cheese as a percentage of the solids-non-fat part of the cheese (protein, minerals, lactic acid plus traces of lactose in freshly made cheese). Cheddar has a typical MNFS of 55%. Longer maturing cheese has lower levels of MNFS.

iii. Salt in moisture (S/M) – This is the salt content of the cheese as a percentage of its moisture content, and is a key determinant of both the rate of maturation of the cheese and its ability to restrict the development of pathogenic bacteria. The S/M range for Cheddar cheese is from 4.5 to 6.0%, with the higher levels associated with more mature cheese.

Yield issues

Cheese yield, the quantity of cheese produced from a given quantity of milk, depends on three key factors:

i. Recovery of milk fat into the cheese (varies between 86 – 92%, typically 90%)
ii. Recovery of milk protein into cheese (varies between 74 – 77%, typically 76.5%)
iii. Moisture content of the cheese

A mass balance approach to cheese yield gives the following equation:

$$Y \text{ (kg cheese/kg milk)} = \frac{F_m \times R_f + P_m \times R_p + X}{(100 - M - S)}$$

Where: F_m = fat content of milk, %
R_f = proportion of milk fat recovered into cheese (e.g. 0.9)
P_m = protein content of milk, %
R_p = proportion of milk protein recovered into cheese (e.g. 0.765)
M = moisture content of cheese, %
S = salt content of cheese, %
X = milk minerals and lactose in the cheese

The factor X depends on the particular cheese recipe used, but a typical figure would be 0.36 for cheddar type cheese. This gives the following equation for the estimation of cheddar cheese yield:

$$Y = \frac{0.9\ F_m + 0.765\ P_m + 0.36}{(100 - M - S)} \quad \text{kg cheese/kg milk}$$

A wide range of processing factors affect cheese yield, particularly milk quality, cheese vat design and curd handling.

Cheese grading and judging

The two tasks, grading and judging, involve the same equipment and techniques but each has a specific and different role within the cheese industry.

Each type and variety of cheese will vary, depending on the ingredients, the main one being the milk. The aim is to make a consistent and acceptable quality product, but due to the vagaries of nature and in spite of the skill of the cheesemaker, that is not always possible. The most successful products are those varieties or types of cheese that have pleased and continue to please the consumer. Each person consuming a portion of cheese acts as a judge, often comparing that particular sample with the memory of a similar cheese eaten previously.

Grading

Grading is the assessment of cheese quality during its maturation, or before being offered for sale and consumption. Variable and poor quality often necessitated cheese to be graded before being sold at various markets/fairs, thus ensuring a reputation for a quality brand at that market or fair. One example was that practiced in the late 19th century at the Market Hall in Caerphilly. Mr Edward Lewis graded and quality branded the various farmhouse cheeses brought for sale there from South Wales

and, if considered to be of the desired quality, it was branded with his official stamp. The practice ceased on his death in 1909.

It is not the intention of this article to describe the various schemes practiced in countries such as Australia, New Zealand and others. Grading schemes were also introduced in the UK. The scheme operated by the National Association of Creamery Proprietors (NACEPE) was widely used up till the 1980s. Points were allocated as follows:

Flavour and aroma	max 45
Body and texture	max 40
Colour	max 5
Appearance (finish)	max 10

Under the NACEPE scheme, cheese was classed as Extra Selected (93 points or more), Selected (83-93 points), or Graded (70-83 points). This national scheme has now been largely superseded by company-specific schemes developed by individual cheese makers and retailers, following the shift from independent retailers to supermarket groups. These schemes are based on sensory profiling but the key attributes in these schemes relate closely to the NACEPE descriptors and the assessment of quality during the process of maturation remains paramount.

The process of grading and judging involves taking a representative sample of the cheese and examining that sample visually and physically – using the eye to see, nose to smell and hand/fingers to feel the body and texture. Various attempts have been made and no doubt will continue to be made, to replace the human senses, but to date none have successfully displaced the person. What constitutes a 'representative sample' merits a separate discussion.

The sample is taken from hard or semi-hard cheese using a 'trier' providing a bore or plug of cheese. Soft cheese is usually cut with a thin long bladed knife and examples are shown in Fig. 9.2.

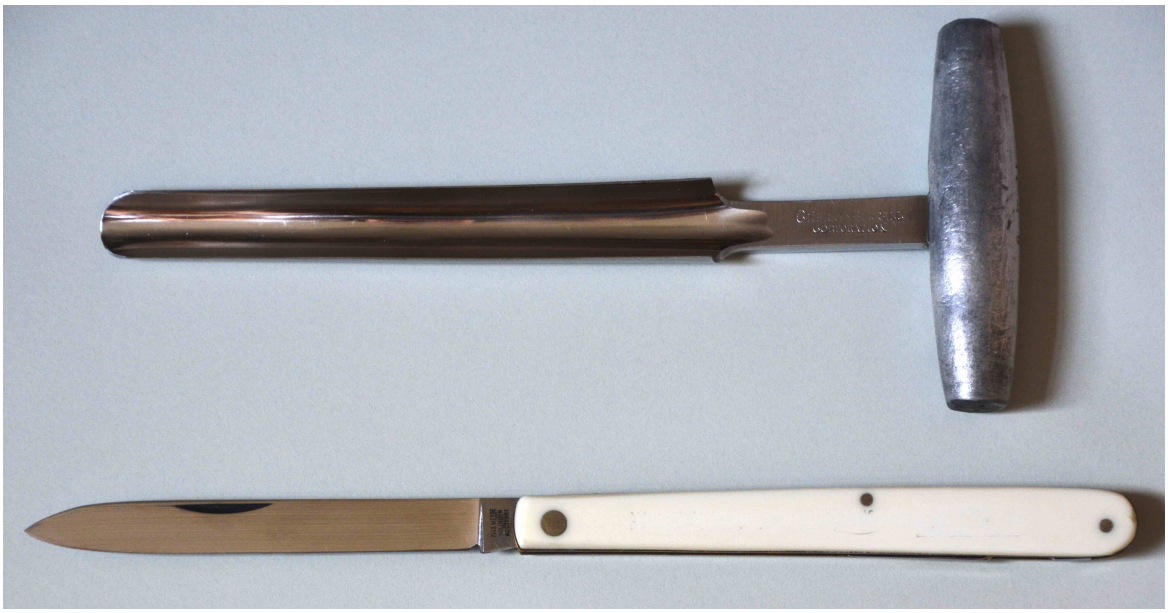


Fig. 9.2 A cheese trier and folding sampling knife

The sample of cheese is normally taken from the top of the block of Cheddar. The pressure needed to insert the trier provides an immediate sensation to the grader as to whether the cheese is weak or firm bodied. A softer or weak bodied cheese can indicate a higher-moisture, more rapidly maturing cheese, made to be sold and consumed as a young cheese, e.g. a mild Cheddar. A firmer-bodied cheese destined to be a mature or vintage brand can be curdy and lacking in flavour at 6-8

weeks of age. An experienced and skilled cheese grader will assess the texture and flavour development, the rate and stage of maturation and advise whether to hold for further maturation for specific brands or aim for a quick sale.

Cheese does not mature according to age. Spring milk will often result in a more rapidly maturing cheese than autumn milk, even when the milk is bulked and from different areas of the country. Grading is a necessary task to ensure that the cheese is sold according to its development and quality rather than age.

What do graders and judges look for?

Appearance – the cheese should be clean and free of defects.

Body and texture – these characteristics should be typical of the variety of cheese. Some of these characteristics have changed with mechanised methods of cheesemaking as well as with today's retail requirements. Judges need to be aware of these changes and while standards of excellence do not change, the typical characteristics may be changed.

Flavour and aroma – again this should be typical of the variety. There should be no taints or off flavours. Some types of cheese such as the smear-ripened cheese have a distinct and, to some, offensive smell. Grading and judging requires knowledge of the varieties and their characteristics especially what is regarded as an unacceptable flavour or aroma.

Little of the cheese is actually tasted by the grader, whereas it is essential for the judge to taste each cheese, which is then normally spat out into a spittoon. Much of the judgement can be ascertained visually, whether the bore of cheese fills the iron or not, whether there are physical defects, such as cracks or slits in the cheese, or an uneven colour. It is also important to look at the back of the iron. It should be clean and shiny for a cheese such as a Cheshire and a young Cheddar. The phrase 'fat on the back of the iron' is often used by graders and judges alike and indicates a mature cheese with more proteolysis. The 'greasy' or 'fatty' appearance, although a good description, has nothing to do with 'fat'!

It is important to smell the cheese, if possible immediately after the sample is taken. Then a small portion of the bore is broken off and squeezed between thumb and forefinger, working it into a soft malleable 'putty' for Cheddar whereas it will form little crumbs with a Cheshire style of cheese. Any physical faults such as lumpiness or graininess is both seen and felt. It is then again smelled and a little of it tasted. It can be difficult to differentiate between one cheese and another, especially when tasting a large number. Mild cheese should always be tasted before stronger and flavoured varieties. A bite of apple helps to revive or cleanse the palate and is considered better than a sip of water. The hole made in the cheese when inserting the trier must be closed and sealed with a small portion of the bore.

Judging

Cheese presented for competition and judging should always be of the best quality for that variety but experienced judges know that is not always so. At most cheese shows, a proportion of the cheeses entered can usually be disregarded because of an obvious fault. It is acceptable to take a sample of a hard cheese such as Cheddar from a block or cylinder to assess its quality before entering it for competition, but care must be taken to seal the hole with a portion of the bore or plug. However that is not possible with soft cheese.

Some cheeses may be presented in proprietary packaging, which may or may not be fully obscured by a blank label. In such cases it is up to the professionalism of the judge to ignore the source when making a judgment. Various scoring systems are used. Some, such as the Wisconsin system, assume a perfect cheese scoring a maximum of 100 points then deducting a few points for

minor defects and more for major defects. This results usually in a range of 10 points and is not a system with wide appeal. The British cheese awards have used a total of 50 points divided as follows:

Appearance	max 10 points
Body & Texture	max 15 points
Flavour & Aroma	max 25 points

The majority of judges use a maximum of 10 or 20 or 25 points and, using their experience and knowledge, award one figure covering all the named attributes.

It was the practice to award one first, one second, etc. prize for each class, but there has been a change of attitude in recent years and at some competitions, a gold award is given to cheese at its prime, a cheese which could be considered 'faultless', with a silver prize to those not quite at their best and a bronze award to very good but not outstanding cheese. Thus more than one cheese in any class could be awarded a gold or silver or bronze, reflecting their quality and providing all such cheese with a worthy accolade.

Whereas the grading of cheese usually takes place in a cheese store and at a constant temperature, many of the larger and well-established competitions take place in cool rooms or areas so that the cheese does not suffer from heat damage. However, this is not always the case and on occasion judges have to take account of poor storage or sub-optimal display conditions. Also, because of the cost, more cheese is being presented for competition as portions rather than the whole block of cheese. On occasion, show conditions fall outside the Food Hygiene regulations and in such cases the cheese is required to be disposed of for processing or destroyed.

Both graders and judges perform an important task within the cheese industry, each complementing the other. Experience and knowledge is required, with the ability to recognise a quality product that will please the consumer.

Further reading

Fox, P.F., Guinee, T.P., Cogan, T. & McSweeney PL.H. (2000) *Fundamentals of Cheese Science*. Aspen Publishing, Gaithersburg.

IDF (1991) *Factors Affecting the Yield of Cheese*. Monograph No. 9301 International Dairy Federation, Brussels.

Law, B.A. & Tamime A.Y (eds.) (2009) *Technology of Cheesemaking.* 2nd edition (Society of Dairy Technology Series). Wiley-Blackwell, Oxford.

Mc Donald I. (2014) *Cutting cheese by wire.* Society of Dairy Technology (available on members' web pages).

Partridge J.A. (2009) Cheddar and cheddar-type cheese. In *The sensory evaluation of dairy products*, 2nd edn, edited by Clark C., Costello M., Drake M. & Bodyfelt F., Springer, New York,. pp 225–270.

Robinson, R.K. & Wilbey, R.A. (1999) *Cheesemaking Practice.* 3rd edition, Aspen, Gaithersburg.

10. Ice cream

Ice cream is the most popular of the frozen desserts in the UK, Europe and North America. Whilst there are no longer compositional standards in the UK, most products contain at least 2.5% milk protein and between 5 and 15% fat by weight. For an ice cream to be described as a dairy ice cream then the fat must be milk fat, except for fats derived from declared ingredients such as emulsifier, egg yolk, chocolate or nuts.

The development of the ice cream market has been dependant on the invention of mechanical refrigeration. Before that the only refrigeration available for freezing the ice cream mix, other than in extreme cold weather, was freezing mixtures of ice and salt. This severely restricted the scale of operation and the shelf life of the resulting ice cream.

Environmental concerns have led to changes in the refrigerants. While some domestic deep freeze cabinets may use hydrocarbon gases, small and medium-scale commercial freezing equipment typically employs R404A, with ammonia still used for large-scale plant.

Formulation

Whatever the scale, the same empirical principles apply to the formulation of ice creams via an unflavoured base mix. The first decision is the desired fat content; the higher the fat then the richer the product (all other factors, such as degree of aeration, being equal). Less efficient freezers usually work better with lower fat mixes. Ideally, fresh cream will give the best dairy flavour but where this is not available then unsalted sweet cream butter or anhydrous milk fat could be used.

The optimum sweetness of an ice cream varies with the market. For the UK market a starting point is:

$$S = 7 + 0.76F$$

where S is the sweetness in sucrose equivalents and F is the fat % (w/w).

The hardness of an ice cream at a given temperature is primarily due to the solute concentration, with sugars being the dominant component. Raising the solute concentration results in a lowering of the freezing point of that solution and hence the proportion of water frozen out as ice crystals. Thus, partial substitution of sucrose by dextrose monohydrate will increase the molar concentration of solutes, depressing the freezing point and conferring a softer texture. Since dextrose monohydrate is less sweet than sucrose, the total percentage of sugars in the mix will be increased. Glycerol may also be used to produce a softer texture. Chocolate mixes are best produced as a separate mix and need additional sweetness to balance out the bitter notes from the cocoa solids.

Traditional ice cream formulations commonly include egg yolk at 1 % (w/w) to aid emulsification. Egg yolk is not an emulsifier in terms of labelling but an ingredient. Where the egg yolk is expected to improve the stabilisation of the product then higher levels must be used, typically in excess of 3 % (w/w). Most commercial ice cream formulations use slightly unsaturated monoglyceride based mixtures at about 0.3 % (w/w) as emulsifier.

Some traditional formulations have used gelatin to increase stability, again this is treated as an ingredient and not as an additive. However, though gelatin gives good flavour release, it is neither a particularly effective inhibitor of crystal growth nor acceptable to vegetarians. More effective stabilisation is achieved commercially by the use of alginates or carrageenans, usually in combination with locust bean gum and/or guar gum at a total level around 0.3% (w/w). Stabilisers are highly hydrophilic and not easy to handle so are usually purchased as integrated blends with emulsifiers. Usage levels vary inversely with fat content.

While 2.5 % (w/w) milk protein represents a former legal minimum, it is not sufficient to provide a high quality product, except perhaps for very high fat ice creams. The optimum level of milk protein lies at a ratio of 1 part of milk protein to 17 parts of water. Since few but the largest manufacturers have sophisticated analytical equipment on site, the easiest approach is to use an alternative ratio of 1 part MSNF to 6 parts water by weight. This is not just added water but that included in any of the ingredients. There is not sufficient protein in bovine milk to provide the desired

protein level in most ice creams so some form of fortification is needed, either a liquid concentrate or, more easily, by adding skim milk powder. Whey powder has been used as a low cost alternative to skim milk powder but can introduce an excessive level of lactose and thus the risk of a sandy texture defect if the substitution exceeds a quarter of the MSNF.

Mix processing

The basic processes of mix manufacture are mixing, emulsification, heat treatment, cooling and aging.

Artisanal producers now have a variety of all-in-one batch processors available, the most common capacities being 60 and 120 litres. While some of the smaller machines use single-phase electricity, the larger machines need a 3-phase supply. Energy utilisation is poor since there is no built-in heat recovery.

Medium to large producers have the option to use either semi-continuous or HTST processes. Semi-continuous processes start with a minimum of two batch tanks, where the ingredients are mixed and heated to the desired temperature, typically 66°C for a 30-minute hold or 72°C for 10 minutes. (Since heat is not easily recovered then the former conditions are preferable if time permits.) At the end of the hold the mix is pumped to a high-pressure homogeniser and then through a plate heat exchanger to cool the pasteurised mix to the ageing temperature.

Ageing

Most mixes benefit from a period of ageing before freezing, carried out at as low a temperature as feasible. This period gives time for additional hydration of proteins and stabilisers, plus further crystallisation of the fats and competition between the surface-active components at the fat globule membranes so that the fat globules are more readily destabilised during the freezing process.

Freezing

Ice cream freezing is a combination of aeration, whipping and freezing processes, whether on a batch or continuous basis. Smaller, batch, freezers may have rotors operating in a vertical or horizontal mode. Vertical freezers are the poorest aerators and typically give overruns of approximately 25 to 50 %, compared to 50 to 75 % for horizontal freezers. These freezer types usually only part-fill the barrel so that the air in the headspace can be folded into the mix as it is frozen. Some larger horizontal batch freezers are sealed and can be pressurised to enable higher overruns to be achieved.

Cooling is provided by evaporation of the refrigerant in the barrel. All but the largest commercial freezers are built with integral refrigeration units that may have either air- or water-cooling. Water-cooled refrigeration units have the possibility for some energy recovery but freezing is the most energy-intensive stage in ice cream manufacture.

Batch freezers are limited in their output, so medium- and large-scale producers will use continuous freezers. These are closed systems where the mix is pumped continuously under pressure through a scraped-surface heat exchanger, whipped and frozen to emerge as a continuous stream of partially frozen aerated ice cream. In the smallest machines, air is sucked into the piston-operated mix pump on the suction part of the stroke; in larger machines lobe pumps are normally used and compressed, filtered air is metered into the mix. The larger continuous freezers employ both feed and exit pumps.

The batch and continuous freezing processes are essentially similar, differing in that batch processes cool a large quantity of mix slowly whereas the continuous process cools a small quantity quickly. Whichever process is used, the ice cream is seldom cooled below -6.5°C, when only about half of the water in the product has been frozen into ice.

Soft-serve freezers are essentially small continuous freezers designed for intermittent operation: thus have relatively underpowered refrigeration systems.

Adding particulates

Batch freezers will tolerate the addition of particulate ingredients, usually towards the end of the process to minimise breakdown in size. Continuous freezers are seldom capable of handling particulates, e.g. fruit conserves, nuts or honeycomb, as they tend to block or damage the pumps, so a separate fruit feeder is needed. Fruit feeders employ a variable speed auger to feed the particulate into the stream of ice cream and the mixture then passes through a variable speed blender, the faster the rotation then the more homogeneous the mixture but the greater the risk of breaking down soft components, e.g. strawberries.

Filling

Small-scale producers often hand-fill but this tends to result in higher give-away, whereas mechanised filling gives better portion control. (In the UK most ice cream is sold by volume rather than weight.) The gaseous portion of the foam structure follows the Gas Laws so the pressure must be kept constant, preferably by including a pressure compensator immediately before the filling head. These systems create a small overflow that can often be recovered by filtering off any particulates, melting and recycling at a low level into the mix tank for a compatible flavour. Packed product must be transferred immediately to the hardening chamber, as any delay will result in melting.

Hardening

Unless the ice cream is to be eaten immediately, then it must be cooled further to below -18°C, preferably to ≤ -27°C for long-term storage. The colder the storage then the smaller the change in the proportion of frozen water with fluctuations in temperature and the slower the rate of migration and hence crystal growth within the product matrix.

Product should be cooled as quickly as possible. The rate of cooling is a function of the temperature differential at the surface of the package and the square of the minimum dimension. Hence, doubling the size of a package will quadruple the cooling rate. It is thus best practice to cool individual packages before placing into any outer packaging and to ensure the highest possible airflow rate over/around the packs. Slow cooling results in larger ice crystals, a coarser texture and shorter shelf life.

Once completely cooled then the product may be placed in any outer packaging and transferred to the holding store, where the lower air flow rate will incur lower energy costs.

Further reading

Clarke C. (2012) *The science of ice cream*, 2nd edition. Cambridge: The Royal Society of Chemistry.

Goff H.D. & Hartel R.W. (2013) *Ice Cream* (7th Edition). New York: Springer.

Tharp B.W. & Young L.S. (2013) *Tharp and Young on ice cream*. Lancaster, Pennsylvania: DEStech Publications.

Weir C. & Weir R. (2010) *Ice creams, sorbets & gelati: the definitive guide*. London: Grub Street. [Reprinted 2012 with minor corrections]

11. Yoghurt

Yoghurt (also sometimes spelt as yogurt) is the cultured milk product made by fermenting the lactose in milk using lactic acid bacteria.
One of the effects of the lactic fermentation is a thickening of the milk as a result of its impact on the native milk protein structure. This thickening process can be supplemented by fortifying the milk protein content, or by the addition of stabilisers and thickeners.
Background science

The flavour and texture of yoghurt are determined by the impact of a relatively high heat treatment on the milk protein system, and by the action of bacterial starter cultures on the milk carbohydrate system (predominantly lactose). These bring about a number of chemical, microbiological and physical changes, as shown in Table 11.1 below.

Table 11.1 Principal changes during yoghurt manufacture

Key Steps	Chemical Changes	Microbiological changes	Physical changes
Heat treatment of milk (e.g. 95°C for 5 min)	Production of growth factors by breakdown of milk proteins	Kills contaminating and competitive organisms	Heat-induced interaction between casein and whey proteins: creates body and texture. Denaturation of whey proteins increases their water binding capacity.
Starter culture addition (*Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*)		Associative growth between lactobacilli and streptococci increases rate of acid and flavour production	
Incubation (typically at 41– 43°C)	Starter bacteria convert lactose to lactic acid (pH reduced to 4.5 – 4.6) Development of flavour compounds (especially acetaldehyde)	Optimum temperature for growth of the starter organisms	Aggregation of proteins contributes to consistency

Manufacturing process

The manufacturing process for the main type of yoghurt (stirred yogurt) is outlined in Table 11.2 on the following page. Variations in manufacturing process for the other types of yoghurt are given under the *Yoghurt varieties and types* section.

Table 11.2 Unit operations in yoghurt manufacture

Unit Operation	Purpose
Pre-treatment of milk plus addition of skim milk powder and/or other dairy powders, sweeteners and stabilisers	i. Control of fat content in final product. ii. Increase protein content for firmer consistency and reduced tendency to whey separation (syneresis). iii. Stabilisers, e.g. pectin, starches, aid firmness and reduce tendency to syneresis iv. Sweeteners increase consumer acceptability
Homogenisation at 60 – 70°C at pressure of 20 –25 MPa	i. Reduce fat globule size and retard creaming rate ii. Modify casein structure to improve water binding and smoothness iii. Improve dispersion of stabilisers
Heat treatment, typically at 90 – 95°C for 5 minutes	i. Eliminate pathogens, contaminants and competitive organisms ii. Induce whey protein denaturation and whey protein/casein complexes which improve water binding capacity and viscosity, reducing the risk of syneresis
Fermentation Inoculation with mixed culture of *Lactobacillus delbrueckii* ssp. *bulgaricus* and *Streptococcus thermophilus* Fermentation typically at 41 – 43°C for 3 – 4 hours	i. Starter culture growth converts lactose to lactic acid & generates flavour compounds. ii. Acidity modifies protein structure to increase viscosity iii. Some fermentations at 37°C for longer time, for different flavour profile
Cooling At pH 4.5, the fermentate is cooled to around 15°C, either in jacketed tank or external heat exchanger	i. Inhibit starter culture growth ii. Stop any further increase in acidity iii. Gentle mechanical cooling to maintain consistency
Structuring Pass through 'structurising' valve or in-line strainer	Improve smoothness of yogurt
Fruit addition Fruit preparation added via in-line mixer	Introduction and mixing of fruit with minimum shear
Packaging Filling into plastic retail containers	i. Maintain product consistency through use of large gap filling nozzles ii. Hygienic filling and good chill chain control gives a shelf-life of 3 to 4 weeks
Storage Blast cooling to <5°C	Improve body and texture, ensuring shelf life

Yoghurt varieties and types

Unlike butter and cheese, there are no legal designations for yoghurt in the UK. Guidance on composition, descriptions, added ingredients and labelling is given in the DairyUK / Provision Trade Federation "Code of Practice for the Composition and Labelling of Yogurt" (2015).

The nature and characteristics of yoghurt texture and flavour profile make yoghurt suitable for flavouring with a wide range of fruit preparations, sweeteners, confectionary and cereals, nuts etc. A range of fat contents can also be found in yoghurts, ranging from 'fat free' products containing less

than 0.5% fat aimed at calorie restricted diets, through to indulgent products which may contain up to 10% fat or more.

Yoghurts and fermented milks are the main dairy category for the delivery of probiotics, i.e. live microorganisms believed to enhance health by improving the balance of microflora in the gut. In addition to the two main yoghurt cultures, such products include bacteria such as *Lactobacillus. acidophilus*, *Lb. casei* and *Bifidobacterium animalis* subsp. *lactis, B. longum* and *B. bifidum*.

Yoghurts are also distinguished by significant differences between the main yoghurt types:

i. Stirred yoghurt
ii. Set yoghurt
iii. Concentrated (or "Greek Style") yoghurt
iv. Drinking yoghurt
v. Pasteurised yoghurt

Stirred yogurt

Stirred yogurt is made by fermenting the milk in tanks, cooling and packing into retail containers as described in Table 9.2. Stirred yoghurt should have a smooth, thick consistency and be sufficiently viscous to hold any fruit pieces in suspension during product life.

Set yoghurt

With set yoghurt, the fermentation takes place in individual retail containers rather than in tanks. Milk pre-treatment is the same as for stirred yoghurt, and then starter culture is added (either in line or in tanks). After injection of flavours and/or colourings, the inoculated milk (at around 42°C) is filled into retail containers and then packed into trays and palletised. Pallets of product are incubated in temperature-controlled chambers until the pH reaches around 4.6, when they are transferred to cooling chambers and then chilled storage.

Set yogurt has a firm, jelly like consistency, which leaves a clean surface when cut.

Concentrated 'Greek Style' yoghurt

Concentrated yoghurts (usually referred to as 'Greek Style' in the UK) are characterised by a significantly higher milk protein level, which results in a particularly thick and viscous body. Originally, these products were made by straining yogurt through a cloth bag to remove whey. Ultrafiltration has also been used in their manufacture, but the two most used technologies are:

i. Concentration and whey removal by processing through a centrifugal separator similar to that used for soft cheese manufacture
ii. Increasing the protein level by the addition of milk powders to the milk base. This is the most commonly used approach in the UK but the use of skim milk powder rather than a milk protein concentrate powder leads to a higher carbohydrate content and a lower protein content, ≈ 4.5% rather than ≈ 9% in the traditional product.

Greek Style yoghurts typically contain 5-10% milk protein, compared with less than 3% in many 'standard' products.

Drinking yoghurt

Drinking yoghurts have the essential flavour characteristics of yoghurt but in a much less viscous form as a refreshing drink. This yoghurt is prepared in the normal way and sweetened with fruit juices and/or sugar. A stabiliser (usually pectin) is added to prevent protein sedimentation, and the mix homogenised to effectively disperse it.

Pasteurised yoghurt

Pasteurised yoghurt has a shelf life of several months and is found in supply chains where chilled conditions are not robust and replenishment of stock is sporadic.

The normal production process involves heat treatment in a scraped surface heat exchanger at 75°C for 15 seconds, followed by hot filling. The heat treatment and filling temperature ensure the elimination of yeast and mould, the key determinants of the shelf life of the fresh product. The heat process does detract from the eating quality of the product, and eliminates any positive nutritional impact of the lactic acid bacteria.

Further reading

Chandan, R, (2006) *Manufacturing Yogurt and Fermented Milks*. Blackwell Publishing, Oxford.

Tamime, A.Y. (ed.) (2005) *Probiotic Dairy Products* (SDT technical series). Wiley-Blackwell, Oxford.

Tamime, A.Y. (ed.) (2006) *Fermented milks* (SDT technical series). Wiley-Blackwell, Oxford.

Tamime, A.Y. & Robinson R.K. (2007) *Tamime and Robinson's Yoghurt Science and Technology*, 3rd edition, Woodhead Publishing, Cambridge.

12. Membrane filtration

Membrane filtration processes are pressure-driven separation processes, similar to filtration but finer. There are two approaches, dead-end and cross-flow.

Dead-end filtration is most commonly used in small-scale laboratory work and where there is a very low level of particles in suspension. The feedstock is pumped to the membrane and the particles are retained on the surface of the membrane to form a cake that acts as a pre-filter. This fouling layer slows up the rate of filtration and eventually stops the filtration process.

Cross-flow filtration is widely used in industrial applications, where the flow is tangential to the membrane (Figure 12.1). The high flow rate creates shear across the membrane surface, the scouring action preventing, or at least reducing the build-up of a fouling layer.

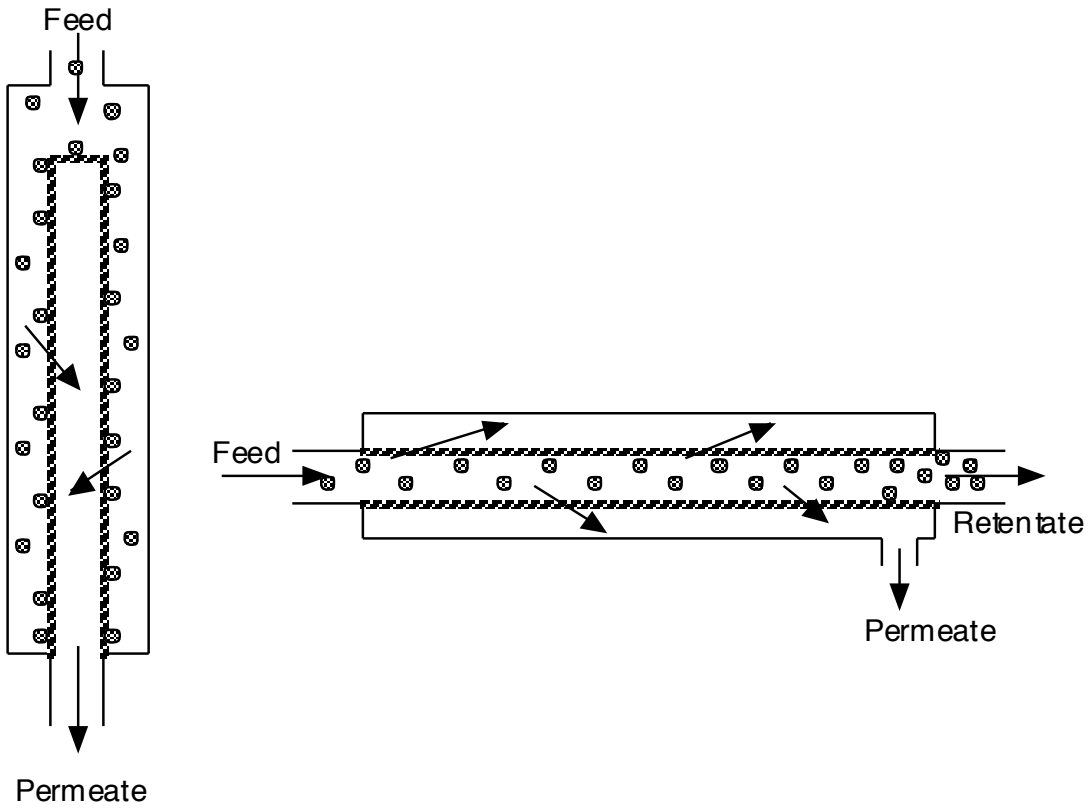


Fig. 12.1 Illustration of dead-end and cross-flow filtration

With increasing fineness, as illustrated in Table 12.1, the membrane can be capable of retaining yeasts, bacteria, viruses (bacteriophages), proteins and other macromolecules, sugars and minerals. The corresponding processes are referred to as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Membrane filtration may also be modified by using an electric field to create selective flow of anions or cations through the membrane in a process called electrodialysis (ED), which has been used widely for demineralisation of whey.

Table 12.1 An indication of the size of material not passing through filters

	Particle size (μm)	MW (Da)
Microfiltration	0.1 – < 10	>200 000
Ultrafiltration	0.002 – 0.1	1 000 – 200 000
Nanofiltration	< 0.001 – < 0.01	150 – 1 500
Reverse osmosis	≤ 0.001	≤ 200

Definitions

Molecular weight cut-off (MWCO) is the nominal molecular weight of a particle that will not pass through the filter. This value is very approximate as passage depends on the shape and charge of the particle.

The *permeate* is the liquid that passes through the membrane, i.e. the filtrate.

The *retentate* is the liquid that is retained, i.e. does not pass through the membrane, and contains a higher proportion of the larger particles/molecules.

Flux rate is the rate of generation of the permeate, commonly expressed as rate per unit of membrane area per hour, e.g. L $m^{-2}h^{-1}$.

Volume concentration factor (VCF or concentration factor – CF) is the volume of feed divided by the volume of retentate. In continuous processes flow rates may replace volumes.

Transmembrane pressure (TMP) is the pressure difference between the mean pressure on the retentate side (high) and the mean pressure on the permeate side (low or zero) and provides the driving force for the process.

Rejection is a measure of the inability of a component to pass through a membrane. Rejection is said to be 100%, when none of that component can pass through the membrane and 0%, when the component passes freely through the membrane, giving an identical concentration of that component on both sides of the membrane. Intermediate values are often found.

Membrane Processes

Concentration

In true concentration all total solids are retained since only water can pass through the membrane (as in evaporation and drying processes), e.g. RO.

Fractionation

Changing the composition by concentrating some components, while others remain unchanged, MF fractionation (MFF), UF, NF.

Clarification

Changing a turbid liquid into a clear solution by removing all suspended and colloidal particles, e.g. MF, UF.

Sterilisation

Removing all microorganisms from a liquid, e.g. tight MF, UF.

Microfiltration

There are two microfiltration processes: removal of biomass, often called 'cold sterilisation' (by MF) and fractionation (MFF). In both applications it is important to operate with low TMP (< 1bar).

Biomass removal

"Cold sterilisation" has been very successful in treating wines, soft drinks and many pharmaceuticals immediately prior to packaging. With milk the presence of casein micelles and fat globules pose problems that limit the process. With skim milk, whey and whey protein concentrates (WPC) it is possible to achieve a 3 – 4 log reduction of total plate counts using ceramic membranes with 1.4 micron pore size. Whole milk cannot be microfiltered due to the presence of milk fat globules, which may block the MF pores. Since only bacteria are removed, this means theoretically no fractionation takes place. However, aggregated protein particles, casein micelles and large fat globules may be partially rejected by the membrane.

With MF, it is possible to produce ESL milk with shelf life up to 28 days at 5°C, or to combine MF with HHT/UHT processes, where the UHT thermal load can be reduced (since MF

removes heat resistant spores) to make new types of market milk products. For cheese milk, MF is used to remove clostridia spores so nitrate addition to the cheese milk can be avoided. For raw milk cheese, the milk can be separated and MF at <40°C on the skim fraction removes critical pathogenic bacteria, e.g. *Listeria* spp. and *Salmonella* spp. by 3 – 3.5 orders.

Cheese brine can also be clarified but, for this application, organic membranes are often used instead of ceramics. MF can reduce high counts of yeasts and moulds to < 10 mL^{-1} and reduces the bacterial load without changing the chemical composition of the brine (which happens during pasteurisation).

MF fractionation

In the protein fractionation processes using ceramic membranes with 0.1 μm pore size, large proteins (casein micelles) are separated from the small soluble proteins (whey proteins). In this way it is possible to concentrate the micelles, which may have applications in production of cheese, fermented products and modified MPC powder. It may be possible to produce caseinate using only membranes.

Ultrafiltration

UF has many applications but, with milk, it is primarily a process for concentration of protein (and milk fat). In the dairy ingredients industry UF is used for concentration of whey proteins from whey into WPC products or for concentrating milk proteins from skim milk into MPC products. The protein content may be concentrated up to 23–27% protein, and in many cases the retentate can be spray dried directly without an evaporation step.

Diafiltration is necessary for higher purity products like WPC 80 (80% protein in the powder or in the solids). In diafiltration, water is added to the retentate and the diluted liquid is then subjected to a further UF process, thus 'washing out' solutes, mainly lactose and minerals, in the permeate.

UF of cheese milk

UF has been used widely in the large-scale manufacture of cheese and fermented milks. Processes can be divided into two groups:

i. *Protein standardisation* – The protein content in the cheese milk is increased, e.g. from 3.2% up to 4.0-4.5%. When this method is used, traditional cheesemaking equipment may be used after UF and the cheesemaking technology involved is largely the same as that used in the traditional cheesemaking. The advantages of this method are savings in cheese rennet, and higher and more standardised cheese yields plus better throughput capacity in existing cheese equipment.
ii. *Total concentration* –Total concentration is a process in which the TS content in the retentate is raised to that of the fresh cheese, giving a cheese process virtually without whey drainage. This method is used for fresh cheeses like quarg, cream cheese, queso fresco and cast feta. Other fermented products such as ymer, yoghurt and fromage frais may also be produced by total UF concentration of the fermentate.

Nanofiltration

NF membranes are tighter than those for UF but slightly more open than in conventional RO. Nanofiltration allows passage of monovalent ions such as Na^{+}, K^{+} and Cl^{-} into the permeate, whereas divalent ions such as Mg^{++} and Ca^{++} are largely rejected by the membrane. The degree of demineralisation, i.e. the % removal of minerals (or ash) from the feed to the permeate, is typically 30 – 40%.

Since some of the monovalent ions are removed from the retentate, the osmotic pressure will be lower than for conventional RO. For this reason it is possible to obtain higher %TS in the retentate than with RO processes. The maximum achievable solids by NF are in the range of 21–25% TS for whey and UF permeates.

Reverse osmosis

In RO practically all the total solids components are rejected by the membrane; allowing only water and similar sized molecules to pass through the membrane. Since virtually all solutes, including ions (apart from H^+ and OH^-), are rejected by the membrane, the osmotic pressure in the retentate will increase and high-pressure pumps are needed to overcome the osmotic pressure. The amount of permeate produced is often referred to as "recovery". For instance, 90% recovery means that 90% of the feed is recovered as permeate (equal to 10x concentration).

Low molecular weight components such as organic acids and NPN components are not fully rejected by the membrane, especially when they appear uncharged (non-ionic), which is typical of weak acids in acidic environments. This is the reason why COD levels in the permeate are higher when processing acid products, e.g. lactic acid whey, than with sweet products such as sweet whey. The maximum solids achievable by RO are in the range of 17-23% TS for whey and UF permeates.

Concentration of milk

Milk contains more than 87% of water. This means that transportation of milk from the dairy farm to the processing dairy is largely transportation of water. Concentration of milk at the dairy farm, using membrane filtration, is a way to decrease costs of transportation and energy use. With increasing herd sizes, this option is becoming more and more attractive to dairy farmers. In New Zealand, milk is already being concentrated at the farm and application of this technology is under discussion in many countries.

Capacity, run time and fouling

A membrane is always exposed to fouling, which will lower the permeate flux and thus the plant capacity. In RO/NF processes this fouling may be compensated by gradually increasing the pressure (TMP) to ensure constant plant capacity. This is more difficult for UF membranes, since raising the feed pressure will increase the flux for a short period only, after which it drops back again to the level obtained before the feed pressure was raised.

A UF plant may start up at 20-50% higher capacity than the designed, average capacity. Usually after 3-4 hours the average capacity is reached and in the remaining production time, the flux decrease will be less rapid. To obtain constant capacity, recycling the initial surplus permeate to the feed tank or putting some loops on hold are ways of compensating for the subsequent fouling and the reduced plant capacity. MF plants are usually operated at a constant capacity, since the TMP is minimised to avoid fouling. Run times are usually 8-10 hours for warm processes (50°C) and 16-20 hours for cold processes (10°C). The limit is due to fouling, build-up of biomass by concentrations or growth and/or compaction of boundary layers, e.g. protein gel layer or fat, leading to changes in the separation characteristics and to reduction of the flux rate.

Membrane types

The earliest membranes were made from organic polymers but have been complemented by (inorganic) ceramics. All types are normally supplied in standard modules.

Organic membranes

First-generation membranes were made from cellulose acetate (CA). These are extremely delicate, not easy to keep in a hygienic state and are seldom used on a production scale other than for some RO applications.

Second generation membranes such as polyethersulphone (PES) and polyamide (PA) are chemically more resistant. These membranes were originally produced as flat sheets for use in a plate and frame assembly. This system has been largely replaced by tubular and spiral-wound (SW)

assemblies. SW elements are most often used for low viscosity liquids since they are cheapest per unit area, compact and easy to replace.

Tubular elements are more suitable for liquids containing large numbers of suspended particles or very viscous products. They are held in perforated stainless tubes, giving high mechanical strength.

Ceramic membranes

Ceramic membranes can be made as both fine tubes and as more complex large tubes. They are extremely resistant to chemical damage but susceptible to mechanical shock.

Cleaning-in-place (CIP)

Membrane plant is generally less robust than most dairy equipment and special cleaning regimes are required. Specialist cleaning and disinfecting agents are commonly required.

CA membranes usually require mild enzyme-based cleaning agents and are readily destroyed by acid or alkaline cleaning agents.

PES/PA membranes will tolerate some alkaline & acid cleaning but concentration & temperature must be carefully controlled. Chlorine and peroxide based disinfectants may be used.

Ceramic membranes may tolerate standard dairy detergents but specialist advice should be sought for the particular membrane.

Water sources

Water classified as 'Drinking Water', i.e. potable, is generally acceptable, on the condition that certain specifications are fulfilled. Softened water is also acceptable, but the conductivity should be above 5 $\mu S\ cm^{-1}$, to avoid prolonging the flushing time and unacceptably high water consumption.

RO permeate and evaporator condensate may contain some organic acids, giving COD levels above 20 $mg\ L^{-1}$. These waters should be stored cold and for as short a time as possible before use. For intermediate flushing this water is fine. For final flushing there will be a risk of bacterial growth when the plant is left closed down. This risk is reduced if the last cleaning step involves chlorinated water.

The hardness of the water is an important factor, as it governs the dosage of the cleaning chemicals and the flushing time. Soft water is the most gentle for the membranes, with a low risk of mineral precipitation on the membrane surface. However, soft water has a much reduced buffering effect when dosing cleaning chemicals, which means that pH limits are reached at lower concentrations.

Further reading

Grandison, A.S. & Lewis M.J. (Eds) (1996) *Separation Processes in the Food and Biotechnology Industries*. Woodhead Publishing, Cambridge.

Lewis, M.J. & Grandison, A.S. (2012) Separations in food processing: part 2 – Membrane processing, ion exchange and electrodialysis, in *Food Processing Handbook*. 2nd edition Volume 2, edited by J.G. Brennan & A.S. Grandison, Wiley-VCH, Weinheim. pp 331 – 362.

Price J. (2013) *A History of the Development & application of Whey Protein Concentrates.* Society of Dairy Technology (available on member's web pages).

13. Evaporation and drying

Evaporation

Milk drying is accomplished in a 2-step process:

i. Boiling milk under vacuum in falling film evaporators in the first instance aims to optimise water removal at temperatures that are favourable for maintaining the wholesomeness of milk while maximising the concentration of milk solids.
ii. The resulting milk concentrate is then spray-atomised in a hot air stream to facilitate final mass transfer of moisture vapour.

Other dairy process streams that are preconcentrated in advance of spray drying include whey, demineralised whey, whey protein retentate, milk protein concentrate and permeate. The extent of concentration depends on a number of factors including initial starting solids and protein content, while rheological behaviour during the final stages of evaporation changes with increase in solids. Whole and skim milk intended for manufacture into their respective milk powders are concentrated to total solids (TS) in the range 42 - 50%, respectively before spray drying. Concentration of milk as a means of reducing cost of transport during trans-shipment between processing centres is frequently practised by evaporation to 30 - 38% TS – the lower solids lessen the risk of product damage and lactose precipitation during transport.

Whey and whey permeate are concentrated to typically 55 - 60% TS in order to induce lactose pre-crystallisation that favours the production of non-hygroscopic whey powder. Small lactose crystal formation is favoured by flash cooling final effect concentrates to 30°C. Recent innovations in whey/permeate processing include the use of 'Hi-Concentrators' that raise TS further to ≈ 70% before final drying in specialised driers. Traditional preserved milk products such as evaporated milk (EM) and sweetened condensed milks (SCM) also require evaporation under vacuum.

Milk evaporators consist of the following components: milk preheater system; vertical tubular-based heat exchangers (calandria) in which a falling of film milk boils under vacuum, milk distribution/tubular wetting system, vapour separation and condensing. Energy recovery is accomplished through use of thermal vapour recompression (TVR) and multi-stage evaporation. In TVR, either single or double steam jet compressors are used to recompress separated vapour across the initial evaporator effects - the pressure (and temperature) of separated vapour is upgraded as a heating medium. Multi-stage evaporation, on the other hand, relies on successive use of separated vapour emerging from each effect to heat the subsequent effect – up to 7 effects may be used. Mechanical vapour recompression (MVR) uses high-pressure fans instead of steam to increase vapour pressure. However, it is not uncommon to find hybrid evaporator systems involving both MVR and TVR. In this format, an MVR evaporator concentrates solids up ~ 40% TS after which TVR evaporation further concentrates to the required solids for drying or processing. MVR evaporators usually have a single effect divided into 5 to 8 stages.

Tube wetting is an important feature of evaporators especially during the advanced stages of concentration according as milk volume reduces and viscosity rises. Split evaporator effects are a mitigating feature of evaporator design to counter this problem and reduce the risk of product burn-on and eventual fouling.

Preheating of milk before evaporation is necessary to optimise water evaporation following entry to the 1st evaporator effect and to bring about required physico-chemical changes, for example to achieve the desired heat classification of the resulting product. Preheating usually commences with initial recovery of energy by pumping cold milk from storage silos through the evaporator condenser and then in counterflow-mode through heat recovery coils attached to each calandria. Given the differential between target preheat temperature in the range 85 – 130°C depending on product and first effect temperature at 68 – 69°C, modern evaporators use direct heating technology to accomplish this objective. Steam regenerated from milk vapour is used to heat milk directly to reach the target temperature followed by flash cooling to just above the boiling temperature of the first effect. In the case of high preheat temperatures, a 2-step heating/flash cooling is employed during the course of ramping-up to reach the target temperature and back down again before entry to the evaporator.

Typical preheat temperatures used during the manufacture of milk powder have been determined over time by the requirements of the heat classification system devised originally by the American Dried Milks Institute (ADMI), now renamed the American Dairy Products Institute (ADPI). The low-, medium- and high-heat powders reflect increasing intensity, respectively of preheating prior to evaporation – the consequence of which is to progressively lower the respective residual undenatured whey protein nitrogen (WPN) content of the powders (see Table 13.1). Medium-heat classified skim milk powder represents the largest category traded. Low-heat may be preferred for certain recombined milk applications that emphasise improved sensory attributes or cheesemaking properties. Adherence to powder microbiological specification may be more challenging during low-heat SMP manufacturing operations due to the lower preheat setting. Another microbiological issue concerns the control of the thermophilic spore-forming bacteria, which may become established in the preheater and early evaporator sections of the evaporator during prolonged periods of operation. Large-scale milk powder manufacturing plants frequently use duplex evaporator systems whereby one evaporator may be in cleaning mode while the other is concentrating product for feeding to the drier.

Milk evaporators may be also fitted with finisher effects – a final effect whereby live steam is used as heating medium in order to provide greater flexibility in terms of controlling product viscosity during the final stages of concentration. This facility enables partially concentrated products, e.g. retentates prepared by membrane filtration processes, to be further concentrated via 'short path' evaporation through the 'finisher' effect before spray drying.

Drying

Roller drying as a form of milk preservation owes its origins to the drying of infant milk formula since the early 1900s. Later, the development of spray driers gained widespread appeal because the milder drying conditions favoured better taste and product functionality following powder reconstitution. Furthermore, economies of scale quickly followed as spray driers became larger and this method of drying became more suitable for processing large quantities of milk. Roller dried milk is still produced to a lesser extent in order to satisfy niche market ingredient opportunities for powder with high free fat in chocolate confectionery manufacture.

Spray drying relies on the transformation of a liquid concentrate into a dried form by spray atomisation of the product into a hot air stream. The fine droplet spray facilitates mass transfer of water in a primary drying chamber – the conventional shape being a vertical cylindrical tower with conical bottom. Other drying chamber designs include flat-bottomed cylinders, tall-form towers and box type driers. Atomisation may be carried out using either a high-speed rotating disk or by high-pressure nozzles. While disc atomisers can handle particulate feeds, pressure jet atomisation generally yields a denser powder with a smaller particle size distribution.

The drying process may be in a single stage or divided into two or three stages, employing an external fluidised bed drier (2-stage) or a combined system with both internal static bed and external fluidised bed driers (3-stage). Evaporative cooling associated with rapid mass moisture transfer from droplets in the primary drying chamber is followed by a much slower rate of dehydration when moisture diffusion kinetics within powder particles take over. Second-stage drying in an external fluidised bed takes place at a lower temperature and in such a manner to avoid overheating of milk powder particles. Powder moisture at approximately 6% entering the external fluidised bed on discharge from the drying chamber is reduced to final product specification, usually < 3.0%. The later evolution of 3-stage drying facilitated a higher moisture powder (up to 10% w/w) entering an internal static bed attached to the base of the drier chamber. The powder discharged from the internal static bed to the external fluidised bed is dried to the final target moisture as already described for two-stage drying.

The above developments in spray drying technology respect the overall need to minimise heat-induced changes in milk concentrates and derivatives, particularly whey-based products that are more susceptible to protein denaturation. At the same time, energy efficiencies have been accomplished through use of higher primary drying air inlet temperatures without penalty to end-product physico-chemical characteristics, e.g. solubility index, scorched particles and browning.

Heat classification of milk powders

The universally recognised heat classification system for skim milk powder originally developed by the ADPI is widely used throughout the dairy industry and commodity dairy product markets. At a basic level, it is a measure of the extent of heat treatment applied in the manufacturing process, principally at the evaporator pre-heater stage. For high-heat powders, corresponding high preheat temperatures are required (see Table 12.1) and *vice versa* in the case of low heat powders. Medium-heat powders are the largest category manufactured but also happen to embrace a wide range of preheating conditions.

Table 13.1 ADPI heat treatment classification for skim milk powder

Class of powder	Undenatured WPN (mg g^{-1} powder)	Guideline heat treatment conditions
Low heat	< 6.0	75°C / 15 s
Medium heat	1.5 – 5.99	85 – 105°C / 60 – 120 s
High heat	> 1.5	120 – 135°C / 120 – 180 s

The interrelationships between manufacturing process parameters and resulting milk powder physico-chemical properties are complex and, apart from the aforementioned preheating conditions, include concentrate type, total solids, viscosity, concentrate heating, spray atomisation type and drier configuration.

The term 'regular' for milk powder usually refers to conventional spray-dried milk powder that lacks instant solubility characteristics when added to water – reconstitution usually requires some mechanical input. So-called 'instant' powders can be accomplished by incorporating agglomeration steps during spray drying. Fine powder particles are harvested from the exhaust air system of the external fluidised bed and recycled by means of a fines return system to the spray atomisation zone of the primary drying chamber, where contact with wet droplets enables clusters of fine particles to form and create larger, porous structures during subsequent drying.

Powder handling systems post-drying should be designed in such a way to minimise the breakdown of such agglomerates. This applies equally to whole-milk and fat-filled milk powders, where powder particle damage can lead to increased free fat levels, particularly when fat in hot powder is liquid; careful attention already having been given to the role of homogenisation in producing a stable emulsion to ensure minimum free fat levels in the subsequent powder.

Sticky products require special attention during spray drying, especially those containing high lactose and other carbohydrates. Whey and whey permeates arising as by-products of cheesemaking may have added complications of high ash and lactate contents. Increased scientific understanding of the state transition behaviour, e.g. the glass transition temperature (T_g) of such products is useful in guiding the selection of appropriate drying process conditions. At an extreme level, specially configured driers that minimise the opportunity of product contact with hot surface may be a preferred option when faced with such drying challenges.

Further reading

Brennan, J.G. (2012) Evaporation and dehydration, in *Food Processing Handbook,* Volume 1, 2nd edition. Edited by J.G. Brennan & A.S. Grandison, Wiley-VCH, Weinheim. pp 77 – 130.

Tamime, A.Y. (ed.) (2009) *Dairy Powders and Concentrated Products*. (SDT technical series.) Wiley-Blackwell, Oxford.

14. Cleaning and disinfecting

The design of modern dairy equipment allows cleaning and disinfecting to take place without the equipment having to be taken apart, i.e. cleaning-in-place (CIP). This means that the processing equipment must be made of materials, primarily stainless steel, that are resistant to the corroding effects of the cleaning agents. The processing equipment, including valves, manifolds and pipelines must also be designed in such way that all surfaces in contact with the product can be cleaned.

CIP cleaning in general

Milk components are excellent substrates for micro-organisms and a carefully designed cleaning programme is thus very important in order to achieve the highest standards of plant hygiene for any high quality product being produced for human consumption. This does not apply only to the parts in contact with the product, but also to the external parts and the general production environment.

The effectiveness of the cleaning is determined by the following interrelated factors:

i. Chemical energy
ii. Kinetic or mechanical energy
iii. Thermal energy
iv. Time

It may be possible to compensate for a deficiency of one of the above energy components by increasing one or more of the other energy factors.

Chemical energy

When CIP systems are used rather than manual cleaning, far more aggressive cleaning agents may be employed. The chemical factor is determined by the cleaning agent and the concentration at which it is used. The cleaning agent is chosen according to the type of soil to be removed, illustrated in Table 14.1.

Table 14.1 Solubility of food soils

Type of Soil	Cleaning agent		
	Water	Alkali	Acid
Carbohydrate	±	+	+
Fat	-	+	-
Protein	-	+	+
Mineral*	-	-	+

*Including water scale

In a centralised CIP plant the majority of the cleaning solution is circulated back to the CIP tanks and reused. Therefore, the concentration may be fixed at a suitable optimum level without leading to excessive waste.

The functions of the cleaning agents are:

i. Wetting to make full contact with the surface.
ii. Penetration to loosen and lift the soil
iii. Dispersion to keep the impurities dissolved or suspended in the cleaning solutions to prevent them from precipitating back onto the cleaned surfaces
iv. Rinsability to enable detergent/soil solutions to be flushed from the surface easily and completely

Concentration of the cleaning agent usually increases with the expected severity of the soil. Typical values are 0.25 – 2.0% w/w for sodium hydroxide (NaOH, also known as caustic or lye) and 0.50 – 1.25% w/w as nitric acid (HNO_3). Dairy CIP systems may also use phosphoric acid or nitric-phosphoric acid mixtures.

Mechanical energy

The mechanical factor is determined by the speed of the liquid over the surfaces. The faster the liquid moves, the more efficient the cleaning process will be. It is important that the movement of the liquid is turbulent, so that there is a scouring action over the surfaces. Consequently, the pump speeds must be considerably higher during CIP than during production. A minimum of 1.5 $m.s^{-1}$ is recommended for turbulent flow for pipeline cleaning. There is no gain in cleaning efficiency if velocity exceeds 2.1 $m\ s^{-1}$.

Cleaning turbines, spray heads and to a lesser extent spray balls in tanks and silos provide an effective mechanical factor (high turbulence), but partial blockages of the turbines may cause problems. Consequently, all cleaning heads should be inspected regularly.

Thermal energy

Temperature is very important. Within chemistry a 'rule of thumb' principle is that the reaction speed doubles if the temperature is increased by 10°C. However, too high a temperature also presents disadvantages, as residues of proteins and lactic salts are precipitated and the solubility of some salts in the water is reduced. Excessive temperature may also reduce the life of pipe seals and heat exchanger gaskets.

Typical CIP temperature ranges are 50 – 65°C for acid solutions and 70 – 75°C for alkali solutions.

Time

Time factors are important for the softening and solubilising of the soil and to ensure all traces of detergent and soil are rinsed away.

Cleaning

The cleaning process of dairy equipment is carried out using a series of discrete stages (or cycles). Not all of the following stages are always included in each CIP programme:

i. Pre-rinse
ii. Detergent circulation
iii. Intermediate rinse
iv. Secondary detergent circulation
v. Secondary intermediate rinse
vi. Disinfection
vii. Final rinse

Pre-rinse (product recovery)

The processing equipment is usually rinsed with cold water, though warm water is preferable for high fat soils e.g. cream. The object is to recover as much as possible of residual product before cleaning commences, using interface detection. The rinse-water containing product residues, also known as 'white water', is not recovered; however, it may be possible to recover milk solids using membrane filtration and thus save on both ingredient losses and effluent treatment costs.

Detergent circulation

The process equipment is cleaned by circulation of a hot alkaline cleaning solution. Many of today's alkaline detergents are highly formulated caustic products, based sodium hydroxide. After cleaning, the cleaning solution should be recovered and re-used. Conductivity control ensures the concentration of detergent remains at its correct value throughout the cycle.

It is also possible to utilise an acidic detergent for this cleaning stage e.g. cold milk areas and under CO_2 environments.

Intermediate rinse
As much detergent as possible is recovered via interface detection with any remaining cleaning solution being flushed out with either collected final potable rinse water or fresh water.

Secondary detergent circulation (optional)
The cleaning of some process equipment, e.g. UHT, is improved by utilising a second detergent cycle, often with a hot nitric acid solution. This two-stage detergent programme may also be used instead of a single stage CIP programme, especially in highly soiled areas, i.e. cheese vats and heat exchangers. Conductivity control ensures the concentration of detergent remains at its correct value throughout the cycle. After cleaning, the detergent solution is collected and reused.

Secondary intermediate rinse
As much detergent as possible is recovered via interface detection, with any remaining cleaning solution being flushed out with either collected final potable rinse water or fresh water. If no disinfection stage is to be employed then the quality of this final water (which is often chlorinated) is critical.

Disinfection
This stage is ideally carried out immediately before the production plant goes back into operation and may be carried out using heat or chemicals, as covered in the following section.

Final rinse
Any remaining cleaning or disinfection solution is flushed out with cold potable water to prevent post disinfection contamination and final product spoilage. Chemical-free water can be collected and used for the pre-rinse stage.

Disinfection

After cleaning, a variety of micro-organisms may remain on dairy processing equipment, even though on visual inspection it may appear to be clean. The purpose of disinfection is to reduce the number bacteria to an acceptable level that will not be a threat to human health or cause product spoilage. This stage is often undertaken cold as an integral part of the central CIP programme. The most commonly used disinfectants are oxidising biocides such as sodium hypochlorite solution (Hypo') or peracetic acid (PAA). It is also possible to use heat in the form of steam or especially hot water but this can prove to be very costly. Start up procedures for heat treatment equipment include programmes for disinfection with hot water using a return temperature at the balance tank of 85–90°C while UHT plants require higher temperatures of 130°C for at least 10 minutes in order to achieve commercial sterility.

General maintenance of CIP plant

Checks can be divided into daily, weekly and monthly:

Daily checks:	Control of alkali and acid cleaning concentrations and the 'condition state' of the solution, i.e. soiling level.
Weekly checks:	Absence of milk stone and lime stone deposits in alkali and water tank/s. Drain off of any bottom sludge from alkali and acid tanks to extend detergent cleaning capacity. Check and clean CIP filters.
Monthly checks:	Condition of various gaskets and replace if necessary. Condition of cleaning solution in both the alkali and acid tanks and change if necessary.

Further reading

Shapton, D.A. & Shapton, N. F. (1991) *Principles and Practices for the Safe Processing of Foods.* Butterworth-Heinemann, Oxford.

Tamine, A.Y. (ed.) (2008) *Cleaning-in-Place.* (SDT technical series) Wiley-Blackwell, Oxford.

Waldron K. (2007) *Handbook of Waste Management and Co-product Recovery in Food Processing.* Woodhead Publishing, Cambridge.

15. Dairy effluent

The wide range of milk and dairy processing operations generate an equally diverse range of wastewaters. Whilst they may have the same broad constituents in terms of traces of proteins, milk fats, lactose and detergents, it would be inappropriate to assume that effluent streams from the production of retail milk would be the same as that from yoghurt or cheese production. Indeed, even the effluent streams from two liquid milk factories may be markedly different, in terms of composition and volume, depending on site wastage management and the manufacturing processes employed. This section of the handbook will provide a brief overview of, and introduction to, the terminology and techniques of basic dairy effluent management.

Tests used for characterising effluents

Oxygen demand

If dairy effluent was to be discharged untreated into a receiving water, there would be a drop in the water's residual dissolved oxygen level. This is due to the effluent's innate oxygen demand, as microorganisms feed on the effluent constituents and use up the available oxygen in the watercourse in the process. In this natural progression, the bacteria are simply using the dairy effluent as a food source, respiring and reproducing, and therefore depleting the available dissolved oxygen in the water. The oxygen demand of an effluent can therefore be defined as the amount of oxygen required to degrade, and thereby stabilise, the organic components of the wastewater. To measure this oxygen demand and other important characteristics, tests were developed for Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) Total Organic Carbon (TOC) and Turbidity.

BOD

The BOD test was developed after the Royal Commission on Sewage Disposal in 1904 and proposed as the standard oxygen demand test. This was to provide an absolute measure of the oxygen required during five days of biochemical or biological oxidation of the wastewater, at 65°F (18.3°C). The test was first known as the 'Dissolved Oxygen Absorption Test' or the 'Royal Commission Test' but was later known as the BOD test.

The BOD test simulates, under laboratory conditions, the biochemical reactions that occur in a natural receiving water when an effluent is assimilated by microorganisms. Factors such as time, temperature, pH and dissolved oxygen content are standardised, thereby enabling direct measurements of relative polluting strengths of various wastewater samples. The current standard method uses an incubation temperature of 20°C and a period of five days, at a pH of between 6.5 and 7.5, and results are milligrams of dissolved oxygen consumed per litre of wastewater, written as BOD_5 in mg L^{-1}. Unless otherwise stated, reported BOD values are usually five-day BOD values, which avoids having to continually write the '5' subscript.

Although the BOD test is widely used by environmental enforcement agencies, treatment plant designers and sewage companies throughout the world, it is not without its problems. Obviously the requirement to hold an incubated sample of wastewater for 5 days provides one of the major drawbacks of this type of test: reaction time for results. Any factory that relied solely on the use of BOD testing would therefore not know whether their discharge was inside the limits set by the enforcement agency for 5 days and this would be clearly unacceptable for modern quality control and assessment parameters. Furthermore, the biological nature of the BOD test also means that the oxidation is under other complications including:

i. Oxygen consumed by the presence of algae since the incubation takes place in the dark
ii. Oxygen consumed by nitrifying bacteria (although these can be suppressed)
iii. Time lag between sampling and analysis at the laboratory
iv. Sterile samples require the introduction of a biological 'seed', increasing the chances of errors

v. Large dilutions are necessary, particularly for crude effluents, exacerbating any errors in testing.

To overcome the problem with nitrification, that is the oxidation of ammonia to nitrite and nitrate, special chemicals can be added to inhibit the nitrifying bacteria without affecting the ordinary carbon-degrading bacteria. In the UK, the chemical used is allyl thiourea (ATU), and when used the result is properly recorded as 'BOD ATU suppressed'. In the USA, the chemical used is trichloro methyl pyridine (TCMP), and again this inhibits any nitrification whilst not upsetting the rest of the test.

Newer developments in the area of BOD measurement have overcome the problem of waiting 5 days for a result by using manometric techniques which directly measure oxygen uptake in the sample bottle. From directly measuring oxygen uptake, and using a good correlation with previous samples, it is possible to estimate, by extrapolation, the BOD after 1 or 2 days, well before the full 5 days are up. Whilst this addresses the problem of immediacy of results, however, the other potential problems are still valid.

In summary, the BOD test is still widely used, and will continue to be, particularly as it is the main parameter used by the Environment Agency in England and Wales for pollution control and enforcement. However, for most analysts the poor record of reproducibility in even the best of laboratories, and its labour-intensive method, mean that the BOD test has largely been superseded in the food industry by the COD test which is more rapid and reproducible, as well as cheaper and easier to complete.

COD

The Chemical Oxygen Demand test was developed in America by scientists looking for a rapid chemical oxidising test without incurring the disadvantages of the old permanganate value (PV), which is now largely redundant. The ease of use of the COD test, particularly in test-tube form, means that it is now the most commonly used parameter for estimating the organic pollution concentration in wastewaters. The modern tests utilise a solution of potassium dichromate ($K_2Cr_2O_7$), in concentrated sulphuric acid with a silver catalyst. Part of the dichromate is reduced in oxidising the organic material in the wastewater and the remainder is determined either by titration with ferrous sulphate or directly by colourimetry or spectrophotometry.

The oxygen demand as measured by this test is based upon chemical reaction between constituents in the wastewater and the test reagents, as compared to biochemical reactions that are measured in the BOD test. As some wastewater constituents are not biologically degradable but can be chemically oxidised, COD values are always higher than respective BOD values of wastewaters. However, the COD test takes around 2 hours, compared to 5 days for the BOD test, which makes the former eminently suitable for routine wastewater and effluent analysis in the dairy industry. Furthermore, a good correlation can be established between COD and BOD on most wastewaters, particularly those in the dairy industry, so it is possible to analyse for COD and use a correlative graph to estimate the likely BOD, if this is required. Figures 15.1 and 15.2 show just such COD to BOD ratios for a dairy effluent at both crude (untreated) and final (after biological treatment) effluents. The ratio of COD to BOD for a crude effluent also gives a good indication on how biologically degradable the effluent is, with ratios less than 2 being fairly easily degradable, whilst those higher than 2 being more difficult to degrade, or recalcitrant.

One drawback with the COD test is that chloride (and also bromide and iodide) ions interfere with the oxidising reactions, giving falsely high results. However, to combat this most modern COD test methods use mercuric sulphate to complex out the halides before digestion. This is suitable for chloride ion concentrations up to 2,000 mgL^{-1}, which is acceptable for most food industry effluents, although those with high salt contents should be checked first.

The most modern method of measuring COD utilizes small test-tubes or vials which are placed in a heated digester block, usually at 150°C for 1 or 2 hours. There are a number of propriety systems on the market, and they are widely used in conjunction with colorimeters or spectrophotometers, to eliminate the need for performing titrations. Open reflux methods are also used in larger laboratories, but these require fume cupboards and specially trained chemists to conduct the analysis. The former tube method is safer, easier to use and has the advantage that plant operators

can be given basic training in the tests, thereby reducing some of the labour requirements (and downtime) in the dairy factory's main laboratory.

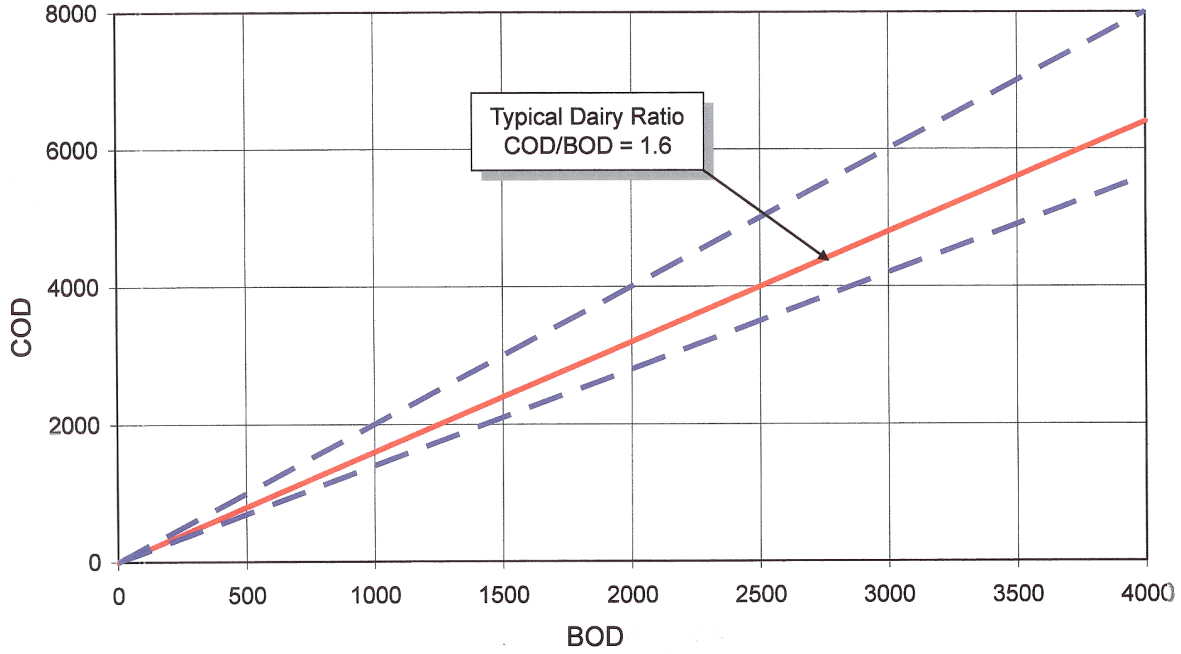


Fig. 15.1 Relationship between BOD and COD (mg L^{-1}) in crude effluent

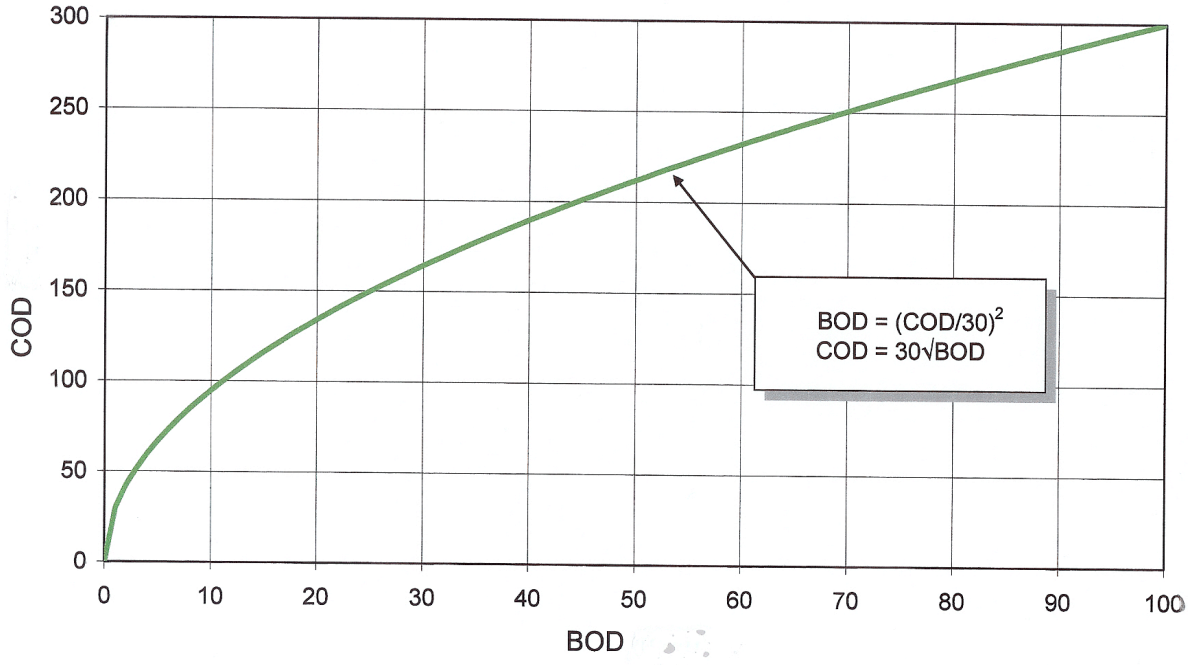


Fig. 15.2 Relationship between BOD and COD (mg L^{-1}) in final effluent

TOC

For the Total Organic Carbon test, the quantity of carbon dioxide produced during complete oxidation is measured. Whilst results are available in minutes, the use of these tests is usually restricted to high level laboratories and their lack of robustness means they are generally not suitable for use outside these premises.

There are also several companies marketing on-line TOC meters. These use ultra-violet promoted persulphate oxidation with infra-red detection of the carbon dioxide formed to continuously determine the concentration of organic material. However, these units are expensive and therefore restricted to either laboratory use or by larger dairy companies. In addition, the on-line TOC meters, particularly those installed on effluent plants, suffer from problems with solids blockages in the very fine sampling tubes, which often necessitates the use of extensive pre-screening, which in itself will reduce the amount of organic material being sampled and therefore falsely lower the result. This problem can be acute for sampling crude effluents, but much less of an issue if sampling final, treated effluents, which will be much lower in solids.

Turbidity

Turbidity is one of the oldest measures for assessing the quality of both treated effluents and raw water, even though there is no exact correlation between turbidity and the other constituents in the sample.

Turbidity is caused a combination of light scattering and absorption by particles in the water. These particles may be clay, silt, organic and/or inorganic materials, plus plankton and other microorganisms.

The oldest method of measuring turbidity or the clarity of the water was by the use of a 20 cm^2 disc with a centrally placed black cross, the intersecting lines measuring 5 cm by 1 cm. The limit of visibility in water or effluent was expressed as the depth in cm at which the cross on the disc just becomes invisible. Some smaller sites still use this method of checking on final effluent quality, and it is possible to produce, for a specific effluent, a rough correlation between depth of visibility and BOD or COD, by conducting a series of tests over an extended period. In an even more empirical test, effluent plant operators use a broom or brush and insert this down into the final effluent until the head just becomes invisible, and then read a series of pre-marked graduations on the broom-handle. This then becomes the “broom test”.

The more modern turbidity tests now use nephelometers, which compare the intensity of scattered light by a sample under defined conditions with the intensity of light scattered by a standard suspension under the same conditions. Formazin polymer is used as the reference turbidity suspension, with the light measured at 90° from its original path. Specially made nephelometric turbidimeters are available from several suppliers, and the test is obviously very quick and easy to do. Results are reported in nephelometric turbidity units (NTU).

In addition, the use of on-line turbidity probes can be used to continuously monitor the quality of an effluent stream, both crude and final effluent. On final effluents, these can be used to provide early warning of problems and be linked to shut-off valves to stop the discharge to a river. On crude effluents, the use of on-line turbidity meters can be very effective at isolating very high strength (high COD) spillages from the dairy, which can then be automatically diverted to a separate tank. The tank contents are then tested for COD and either tankered off site or bled slowly back into the effluent stream if plant conditions warrant. In both cases, a series of approximate correlations between turbidity and COD are made.

With crude effluents, on-line turbidity meters can be linked with flow meters to provide data for estimating losses from individual CIP or floor drains within a large dairy, to provide excellent levels of departmental accountability for wastage. In the state-of-the-art Almarai Company dairy factory at Al Kharj, Saudi Arabia, just such a segregation and effluent monitoring system was designed to provide real-time data on losses, linked to the overall factory management information system. This system ensured that the losses were controlled to very low levels, and has been instrumental in ensuring that this factory had the lowest wastage compared to similar milk processing plants anywhere in the world. The factory won the “World’s Best Food Factory” award in 1998.

The importance of effluent loading

One important parameter that has yet to be mentioned is effluent flow, or volume. The quantity of wastewater produced by the range of dairy and milk-processing factories varies enormously and accurate flow measurements are essential for determining the hydraulic loading of the effluent plus, as detailed below, the organic loading.

Each processing plant must provide suitable means for measuring and recording the volume of its effluent. This is especially critical in factories with on-site effluent treatment facilities, but also those that discharge to municipal sewage works should monitor volumes carefully. There are many suitable instruments for monitoring effluent volumes that can be installed in drains, tanks or be attached to pumps. Accurate volume information is required to properly design and manage wastewater treatment facilities and to evaluate the effectiveness on any in-house wastage reduction campaigns.

Most importantly, accurate volume data is needed in order to calculate the organic loading of the wastewater, one of the most critical numbers used in effluent and wastage management. From the information above, one can assess an effluent's organic oxygen demand (BOD and/or COD), which will give a good indication of how much oxygen will be required to oxidise the effluent. However, measurement of the concentration of COD alone will only give us a measure of the organic strength of the effluent stream, in mg of oxygen per litre of effluent. Thus, in order to determine the total organic load of the effluent, the volume and strength of effluent that is being discharged must also be known. The organic loading can be estimated as follows:

$$\text{kg COD} = \frac{\text{COD (mg L}^{-1}\text{) x Volume (m}^3\text{)}}{1000}$$

or,

$$\text{kg COD} = \frac{\text{COD (mg L}^{-1}\text{) x Volume (L)}}{1{,}000{,}000}$$

Organic loading is expressed as a weight in kg COD (or kg BOD), and provides a measure of the total pollution load in the effluent. These calculations are critical in the design and management of effluent treatment plants, as well as in effective wastage control in the dairy. The overall loading of the effluent is **most** important when considering its environmental impact and not just concentration – one **must** take into account both volume and strength. Thus, in summary, when we talk about effluent loading, we are usually referring to:

Hydraulic loading, m^3 (often measured per day, in $m^3 day^{-1}$)
Organic loading, kg COD (often also measured per day, as kg COD day^{-1}).

Product equivalents

The COD, in both mg L^{-1} and kg COD m^{-3} for some of the main milk and dairy products and byproducts is shown in Table 15.1 on the following page, highlighting their huge pollution potential. Having knowledge of both the effluent loading (in kg COD day^{-1}) and the COD of the dairy product makes it possible to calculate the product equivalent of any organic loading. For instance, consider a retail milk dairy with an average daily effluent loading of 2,950 kg COD.day^{-1}.

The product equivalent (in milk) of this dairy can be calculated as follows:

$$\text{Product equivalent (m}^3\text{)} = \frac{\text{effluent loading (kg COD)}}{\text{COD prod equivalent (kg COD.m}^{-3}\text{)}}$$

$$\text{Product equivalent (m}^3\text{)} = \frac{\text{2 950 kg COD}}{\text{220 kg COD.m}^{-3}}$$

$$= 13.409 \text{ m}^3 = 13\,409 \text{ L of milk}$$

Thus, this dairy with average daily effluent loading of 2,950 kg COD.day^{-1} is losing the equivalent of around 13 400 L milk per day to effluent.

Table 15.1 Typical oxygen demands for milk and milk products

Product equivalent		COD (mg L^{-1})	COD (kg COD m^{-3})
Whole milk		220 000	220
Chocolate milk		250 000	250
Semi-skimmed milk		165 000	165
Skimmed milk		105 000	105
Jersey milk		250 000	250
Jersey skim milk		108 500	108
Cream	50% fat	1 550 000	1 550
	42% fat	1 323 000	1 323
	16% fat	475 000	475
Buttermilk		100 000	100
Skim milk concentrate	52% TS	415 000	415
2% sugar solution		22 400	22
Raw whey		82 000	82
Separated whey		62 000	62
Press Whey		150 000	150
Hastener whey (Stilton)		90 000	90
Whey concentrate	42% TS	486 000	486
	50% TS	578 000	578
	65% TS	750 000	750
Milk separator de-sludge		110 000	110
Buttermilk separator de-sludge		85 000	85
Fruit yoghurt (average)		312 000	312
Fruit dairy ice cream (average)		445 000	445
Beer (bitter)		119 000	119
Vinegar		72 000	72
Whisky (blended)		600 000	600
Irish cream liqueur		875 000	875
Apple juice		150 000	150

N.B: This data has been calculated using standard vial-based COD testing equipment on serial dilutions. It is recommended that these figures are used as guide values only, and further tests completed on your own site and products to check accuracy.

Dairy wastage management

In assessing the wastage efficiency of a variety of dairy and milk processing sites, the two main wastage coefficients used are:

i. % COD (or % milk) loss.
ii. The ratio of effluent to milk (or intake).

These techniques have been used for many years, and have proven to be much more accurate than trying to assess percent milk loss using yield calculations or mass balances. Indeed, the integrated pollution prevention and control (IPPC) guidelines for the dairy and milk processing sector in the UK suggest that these coefficients are the best way of measuring wastage at milk processing sites on an on-going basis.

For information, a detailed statistical report completed for a major dairy company showed that the variance errors in the mass balance calculations for assessing the sites' wastage performance were

ten times the % COD loss assessed. This highlights that trying to assess wastage to effluent by using yield calculations is inherently inaccurate.

To calculate the % COD loss to effluent for a particular site, the procedure is to use the effluent loadings and compare this against the milk and ingredient intake, converted to kg COD, as follows:

$$\% \text{ COD loss} = \frac{\text{Effluent loading (kg COD)}}{\text{Milk intake (as kg COD)}} \times 100$$

The standard COD values of milk and other main ingredients may be used, as detailed in the Table 13.1, with whole milk having a COD of 220 000 mg L^{-1} or 220 kg COD m^{-3}. For very accurate results, it is necessary to convert all the ingredients into their COD value, including other liquid and solid products that enter the dairy, e.g. cream, buttermilk, concentrates, vegetable oils and sugar.

The ratio of effluent to milk (or effluent to intake) is simply the ratio between the amount of effluent generated compared against the corresponding milk or product intake. As with the figure for percent COD loss, this allows for comparison across similar processing sites, so that individual dairies can be benchmarked. As a worked example, consider a retail milk dairy having an average daily liquid milk intake of 550 000 L day^{-1}, with an average daily effluent loading of 990 m^3 day^{-1} and 2 950 kg COD day^{-1}. The dairy would have an effluent:milk ratio of 990/550 or 1.8:1. This means that for every litre of milk that enters the dairy, some 1.8 litres of effluent are produced.

For % COD (milk) loss:

$$\% \text{ COD loss} = \frac{\text{Effluent loading as kg COD}}{\text{Milk intake (as kg COD)}} \times 100$$

$$\% \text{ COD loss} = \frac{2{,}950 \text{ kg COD} \times 100}{550 \text{ m}^3 \times 220 \text{ kg COD.m}^{-3}}$$

(Where 220 kg $COD.m^{-3}$ is the COD equivalent of milk – see Table 13.1)

$$\% \text{ COD loss} = \frac{2{,}950 \text{ kg COD} \times 100}{121{,}000 \text{ kg COD}} = 2.438$$

Thus this dairy is losing an average of 2.44% of its milk intake, or around 13,409 litres per day of milk equivalent.

As with any management regime, effective monitoring is vital for dairy wastage management to obtain accurate information on the size of the problem and how effective the action is in tackling the issue. It is strongly recommended that the wastage coefficients used above are calculated on a daily basis, with results graphed so that trends can be observed. Table 15.2 on the following page shows a range of “excellent” and “average” wastage coefficients across a variety of dairy and milk processing operations.

Table 15.2 Examples of wastage coefficients from dairies

Type of milk processing plant	Excellent		Average	
	Effluent:milk	COD loss (%)	Effluent:milk	COD loss (%)
Retail milk [1]	0.5:1	0.5	2.0:1	2.25
Multi-product[2]	1.25:1	1.5	2.5:1	4.5
Butter & spreads[3]	1.2:1	0.8	1.5:1	1.3
Cheese – no whey processing[4]	0.75:1	0.85	1.0:1	1.2
Cheese with whey processing[5]	2.0:1	1.85	2.5:1	2.8

[1] Retail milk dairy includes both NRC and glass bottling

[2] Multi-product dairy includes yoghurt, cream, fruit juice and milkshake production but is still predominantly milk based.

[3] Butter and spreads includes traditional creamery operation (from milk and sub-purchase cream) as well as scraped-surface technology.

[4] Cheese with no whey processing includes the smaller, hand-made operations with no or limited whey processing, e.g. occasional whey butter, but no concentration or drying

[5] Cheese factories with whey processing are the larger operations with full whey concentration, processing and drying.

Further reading

Von Sperling M. (2007) *Wastewater characteristics, treatment and disposal.* IWA Publishing, London.

Wilbey, R.A. (2012) Water and waste treatment, in *Food Processing Handbook*, 2nd edition Volume 2. Edited by J.G.Brennan & A.S. Grandison, Wiley-VCH, Weinheim. pp 593 – 621.

16. Waste management

Both the cost of raw milk and its potential for pollution have provided good stimuli for the dairy industry to minimise waste and to exploit by-products. Liquid waste is discussed in the earlier section (see *Effluent*). Legislative and consumer pressures to reduce packaging waste and increase recycling rates have added to economic incentives and the constant drive to reduce energy and other costs. For instance, over the 30 years from 1970 there has been a 35% weight reduction in the weight of milk bottles, the traditional milk packaging associated with doorstep deliveries, thus reducing the costs of both packaging and transport. Plastic bottles were introduced in around year 1998 with, for instance, a 2.23 L (4 pint) bottle weighing 42 g, which has now been reduced to only 34 g.

Food

While most dilute liquid waste would be treated as effluent, some more concentrated and solid sub-standard products may be created, for instance as a result of mis-processing. Where this cannot be reprocessed then disposal is necessary. Alternatives are dilution on-site and disposal through the plant's effluent plant, dispatch for treatment at an anaerobic digestion plant or through conversion to animal feed. Guidance on the latter route is given by DEFRA (2014).

Packaging

The Waste Framework Directive sets out an hierarchy in the handling of waste. Priority is given to prevention – avoiding waste in the first place. If waste has been created then it should be prepared for re-use with recycling as the third step, for instance by cleaning and checking. Waste that cannot be recycled by current techniques may be subjected to other processes such as anaerobic digestion, incineration or pyrolysis that have the potential to recover energy and reduce the quantity of material going to disposal as landfill.

In any reuse or recycling scenario it is important to be able to identify the materials. In the case of plastics, manufacturers have been encouraged to mark the items with an identifying code, with a number in an arrowed triangle, below which is an abbreviation for the plastic, as listed in Table 16.1. This list is by no means exclusive and omits many polymers used in dairies, such as polycarbonate for safety screens and shatterproof glazing.

Table16.1. Identification codes for plastic packaging materials

Codes on material		*Full name*	*Typical uses*
1	PET	Polyethylene terephthalate	Water bottles, soft drinks, jars, tray lids
2	HDPE	High density polyethylene	Drums, milk bottles, food wrapping, carrier bags
3	V	Polyvinyl chloride (PVC)	Cling film
4	LDPE	Low density polyethylene	Squeeze bottles, bags and sacks,
5	PP	Polypropylene	Containers & lids
6	PS	Polystyrene	Single portion containers
	Other	(Other types of polymer)	

Product packaging

Glass was the primary packaging for liquid milk in the UK but now occupies a minor niche in the market, primarily for some doorstep deliveries where multiple re-use justifies its retention. Where glass cannot be reused then recycling uses less energy than glassmaking from raw materials.

Most liquid milk is now packed in HDPE bottles and sealed with a foil composite plus an LDPE cap, or in card composite cartons. Large bottling plants may have an on-site blow-moulding unit and any malformed or damaged clean bottles could be chipped and recycled to the melt tank. Any dirty plastic will need washing and find another route.

Card composite material is difficult to reuse as the PE liner, and probably an aluminium foil layer in ESL and UHT packs, make recycling difficult. Incineration and energy recovery has been used for these materials.

Large dairies often use form-fill-machines for yoghurt and similar products. Packaging design should blend consumer appeal with minimisation of waste when the web is cut after filling and sealing. Any residues of foil need to be removed from the remaining web to create two waste streams. Single polymers such as PS are then easy to recycle but the introduction of barrier layers into the web material for extrended life products makes recycling more difficult, the material probably only being fit for a low-grade mixed plastic use.

Smaller dairies and product lines typically use pre-moulded printed containers, PS remaining popular for short shelf life products. Wastage can be minimised by avoiding damage in handling and by storing under cool ambient temperature and avoiding moisture.

Outer packaging

Wooden pallets are often of dubious hygienic quality and should be kept dry, outside clean areas, for despatch/return to suppliers.

Films and many ingredients and other supplies are usually shrink-wrapped onto pallets. The shrink-wrap should be removed and collected for recycling.

Pre-formed and printed containers are usually supplied in PE liners within cardboard boxes. When the containers are removed from the boxes, the boxes can be folded down and stacked onto a pallet, sometimes for return to the supplier but usually for sale to a recycler. The PE liners should be collected separately.

Where product is dispatched to a wide range of retail outlets then it is common to pack retail portions into cardboard trays, sometimes with plastic overwrap. Storage under clean dry ambient conditions will minimise wastage.

With larger retailers where outer packaging can be returned to suppliers, then reusable and stackable or foldable plastic trays have been adopted. While this system reduces the potential wastage of outer packaging, additional tray-cleaning facilities must be introduced at some stage of the cycle.

Energy

The general principle is that it is better to avoid expending energy in the first place than to have to recover it at additional cost. The most common example in the dairy industry is the use of regeneration during the heat treatment of milk, where more than 95% of the nominal thermal load may be provided by regeneration (see *Pasteurisation*). This principle can be applied to most continuous thermal processes.

Lighting must be sufficient for the needs in an area. In most cases indirect sunlight is not possible or appropriate and LED-based lighting is now the least energy demanding.

Appropriate sizing and variable speed control of motors will reduce energy demands, possibly overshadowed by the constant need to optimise processes, including CIP processes.

Cooling is typically the largest user of electric power in a dairy plant. Often technical departments demand very low exit temperatures from pasteurisers and in product storage. It should be noted that energy used for cooling/keeping milk at i.e. 2°C is about double the energy required to cool/keep the milk at 5°C. Cold stores also put big demands on power for their refrigeration systems and again the set point for the temperature has a very high impact on energy usage. Both cold stores and cooling systems must be well insulated, as a large part of the energy can be wasted this way. Not only should the refrigeration systems be optimised for the anticipated cooling loads but measures should be taken to ensure that they stay optimised. A well-maintained system uses less energy.

Energy recovery

Where energy cannot be recycled easily, as in regeneration systems, indirect means may be employed such as using heat pumps. Heat pumps can be used to remove heat from a relatively low-grade 'waste' stream and transfer that heat into a more useful utility such as a hot water service or for space heating in winter. Apart from capital cost, these systems also increase consumption of electric power and require good constant sources of heat, storage systems and good constant outlets for the energy as well.

Food chain management

Most dairy companies are involved in the aquisition of raw milk as well as despatch and delivery of their products.

Strong off-odours, high temperature or acidity can be identified before loading a tanker but antibiotic residues cannot and may lead to the rejection of a whole tanker-load of milk. A good relationship between dairy and supplier is essential in avoiding this problem.

The shelf life and quality of dairy products is dependent on maintaining the chill chain throughout the products travel to the customer. Not only must the dairy's cold store be maintained at the optimum temperature but all transport vehicles must be running at the specified temperature or the delivery might be turned away at its destination.

Further reading

Bourakis M.A. and Weighman P.W.H. (Eds.) 2004) *Food supply chain management*. Blackwell Publishing, Oxford.

Department for Business Innovation & Skills (2015) *Packaging (Essential Requirements) Regulations: Government Guidance Notes*. [Accessed 8th April 2018] https://**www.gov.uk**/government/uploads/system/uploads/attachment...

Department for Environment, Food and Rural Affairs (2014) *Using leftover milk and milk products as farm animal feed. https://www.gov.uk/guidance/using-leftover-milk-and-milk-products-as-farm-animal-feed. [Accessed 8th August 2018]*

Eastham J.F., Sharples L. ans Ball S.D. (Eds) (2001) *Food supply chain management: Issues for the hospitality and retail sectors.* Routledge, Abingdon.

Pullman R. and Wu Z. (2011) *Food supply chain management: Economic, social and environmental perspectives*. Routledge, Abingdon.

Robertson G.L. (Ed.) (2010) *Food packaging and shelf life: A practical guide.* CRC Press, Boca Raton.

Waldron K. (Ed.) (2009) *Handbook of waste management and co-product recovery in food processing.* Volumes I & II, Woodhead Publishing, Cambridge.

Wang L. (2009) *Energy efficiency and management in food processing facilities.* CRC Press, Boca Raton.

Yam K.L. and Lee D.S. (Eds.) (2012) *Emerging food packaging technologies: Principles and practice. Woorhead Publishing, Oxford.*

17. Maintenance

A good and well-structured planned maintenance programme is the cornerstone of any successful manufacturing site. Maintenance is often something that goes on in the background and the positive impact of well executed maintenance is experienced in the long term. However, due to economic and other pressures, maintenance is often overlooked and short-term measures prioritised.

When maintenance is set up properly and working well then you will see the following benefits:

i. Accurate equipment maintenance, repair, and replacement records become available.
ii. There is increased availability of production systems and equipment.
iii. Fewer failures of production systems and equipment occur, resulting in fewer unplanned outages.
iv. Improved product quality, associated with a reduction in costs related to loss or reprocessing of product.
v. Lower longer-term costs for system and equipment maintenance, spare parts inventory and capital replacement.
vi. Enhanced morale among management and the workforce as they learn to enjoy a proactive environment instead of surviving in chaos.
vii. Additional real production capacity, since operating units are able to operate at higher output levels for sustained periods without excessive equipment failure.
viii. Higher profits from the compounded effect of reduced conversion costs and increased production levels

Setting up a good maintenance organisation with the right skills, systems and ways of working is a significant job that takes both time and dedication. Sites that are world class today have started by setting a clear strategy for maintenance and have been on a minimum 3-year journey to be where they are today.

Calibration of process monitoring instruments

Purpose

This Code of Practice for Process Monitoring Instruments (PMIs) is intended to contribute to the production of safe food by reducing the risk of bacteriological contamination. It is also intended to contribute to the maintenance of a high product quality, thereby securing a high customer satisfaction, and to assure that the correct standards are achieved for heat-treated products. It applies to all PMIs in milk processing.

Procedure

Full calibration need not be applied to every PMI used in dairies. This is because calibration of some instruments is not required where it is uneconomical, technically unnecessary or because the accuracy of the instrument has no effect on the overall quality target. Instruments are therefore divided into three groups according to their criticality to the process, as shown in Table 17.1

Table 17.1 Instrumentation risk definitions

High risk	Medium risk	Low risk
Instruments that if inaccurate might affect food safety and/or are used where it is necessary in order to meet legal requirements.	Instruments that if inaccurate might affect the product quality or other process parameters, thereby raising cost and wastage.	Items that are installed to provide general information of a process parameter and are not considered critical to any aspect of the process.

It is still important that low risk instruments are checked regularly, to make sure they work. If the instruments are broken or clearly out of range, they should be withdrawn, and either scrapped or clearly marked to prevent them from being accidentally put back into use before corrections have been made to the instrument.

Temperature

Temperature is an important parameter of dairy processing. One of the most important parts of most processes is pasteurisation, where the product is heat treated in order to reduce the risk of bacteriological contamination. Temperature is also important in CIP, because the chemicals need to be heated to a certain temperature in order to successfully remove soil and reduce the risk of microbial contamination. When storing products, temperature also plays an important part, because storage at incorrect temperatures, will affect the quality of the product. Different components are used in monitoring and controlling temperature:

Resistive thermal devices (RTDs) are temperature sensors that measure the increase in the electrical resistance of materials related to a change in temperature. A typical RTD uses a Pt-100 sensor, taking advantage of the virtually linear change in the resistance of a platinum wire with temperature. Thermistors may be used in some laboratory instruments, e.g. cryoscopes, where very small temperature changes need to be measured over a relatively small range of temperature. Thermocouples are combinations of dissimilar metals whose junctions produce a voltage that varies non-linearly with temperature.

Temperature transmitters are signal converters that convert the signal from a sensor or transducers into an output, representative of the sensed temperature, that can be transmitted to a controller or recorder at a remote location such as a control station.

Temperature measuring systems are usually calibrated against a "Working Standard". A Working Standard is an instrument with an accuracy that is traceable to national standards, has been certified by UKAS and is kept solely for calibration purposes. Copies of certificates that display a UKAS centre number and logo indicating calibration are the only proof that calibration to national standards has been attained, and must be held on site.

According to their criticality, the PMIs are listed in Table 17.2. If an inspection proves that the actual condition of certain PMIs dictates different intervals, then the interval can be adjusted accordingly. Any change in intervals must be documented with observations regarding condition and with nature of the change.

Table 17.2 Examples of temperature measurement requirements and calibration procedures

Risk level	High	Medium	Low
Accuracy	± 0.4°C in the range of 0–150°C	± 1°C in the range of 0-150°C	>1% of measuring range
Examples	Divert control on pasteuriser CIP sterilising temperature	Cold store tanks CIP return temperature	Effluent water
Recommended instruments	Pt-100 from a reputable supplier	Pt-100 from a reputable supplier	No recommendations
Calibration intervals	6 monthly	12 monthly	When practical
Calibration method	i. The Working Standards used for calibration must be traceable to national or international standards. ii. Working Standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. The method of calibration must be according to international standards such as ISO 9000 and ISO 17025 and accreditation held for this method. iv. The person performing the calibration must be adequately trained, as required by ISO 10725.	i. The Working Standards used for calibration can be a local standard but must be traceable to national standards. ii. Working Standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. Calibration may be performed by a person trained to at least level 3 in food safety and hygiene and who has received specific training.	No specific method required
Documentation	1. Calibration records must include documentation that calibration of PMIs has been held up against a Working Standard in order to be valid. 2. Records must be kept for at least 2 years. All calibrated instruments, should be listed as in Annex 1.	i. Calibration records must be kept for at least 2 years. ii. All calibrated instruments, should be listed as in Annex 1.	No documentation required

Pressure

Pressure plays an important part in dairy processing. If there for example is a leak in one of the plates in a pasteuriser, it is important that the pressure is higher on the pasteurised product side, in order to avoid contamination by the heat exchange medium. In the regeneration stream it is also important to have a correct pressure difference, so that unpasteurised product does not enter the pasteurised stream. Pressure measurement is very important in this case.

A pressure sensor is the instrument that measures the pressure. One type of pressure sensor is in contact with the pressure of the process stream by an isolation system, which can be a diaphragm and an isolating fluid between the sensor and diaphragm.

A pressure transmitter is a signal converter that converts a sensor's or transducer's signal into an output representative of the sensed pressure. Pressure transmitters are used in controlling pressure processes by transmitting the signal from the sensor to a remote location. The output of the transmitter can be transmitted to a control room or to another process device, such that the process can be controlled and monitored.

When calibrating pressure measuring systems they are usually compared against a "Working Standard". A Working Standard is an instrument with an accuracy that is traceable to national standards, has been certified by UKAS and is kept solely for calibration purposes. Copies of certificates that display a UKAS centre number and logo indicating calibration are the only proof that calibration to national standards has been attained, and must be held on site. According to their criticality, the PMIs are listed in the Table 17.3.

If an inspection proves that the actual condition of certain PMI's dictate different intervals, then the interval can be adjusted accordingly. Any change in intervals must be documented with observations regarding condition and with nature of the change.

Table 17.3 Examples of pressure measuring systems and their calibration

Risk level	High	Medium	Low
Accuracy	± 0.1 bar in the range between 0 and 10 bar	± 0.2 bar in the range between 0 and 10 bar	> 0.2 bar in the range between 0 and 10 bar
Examples	Pressure difference in pasteuriser	Level in storage tanks	Compressed air
Recommended instruments	Hydrostatic pressure sensor From a reputable supplier	Hydrostatic pressure sensor From a reputable supplier	No recommendations
Calibration intervals	6 monthly	12 monthly	When practical
Calibration method	i. The Working Standards used for calibration must be traceable to national or international standards. ii. The Working Standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. The method of calibration must be according to international standards such as ISO 9000 and ISO 17025 and accreditation held for this method. iv. The person performing the calibration must be adequately trained, as required by ISO 10725.	i. The Working Standards used for calibration can be a local standard but must be traceable to national standards. ii. The Working Standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. Calibration may be performed by a person trained to at least level 3 in food safety and hygiene and who has received specific training.	No specific method required

Documentation	i. Records of calibration must include documentation that calibration of PMIs has been held up against a Working Standard in order to be valid. ii. Records of calibration must be kept for at least 2 years. iii. All calibrated instruments, should be listed as in Annex 1	i. Records of calibration must be kept for at least 2 years. ii. All calibrated instruments, should be listed as in Annex 1	No documentation required

Flow

The measurement of the flow rate is important to the dairy process. It helps in quantifying the materials flowing through the system, which is important from a financial point of view since it gives an approximation of the amount of product and wastage produced.

Flow meters are used for measuring the flow rate of a process stream. One type of liquid flow meter is called an electromagnetic flow meter. These flow meters create a magnetic field and two electrodes measure the voltage induced in the fluid and relate this to a flow rate.

A flow transmitter is a signal converter that converts a sensor or transducers signal into an output representative of the sensed pressure. Flow transmitters are used in controlling flow processes by transmitting the signal from the sensor to a remote location. The output of the transmitter can be transmitted to a control room or to another process device, so the process can be controlled and monitored.

When calibrating flow measuring systems they are usually held up against a "Working Standard". A Working Standard is an instrument with an accuracy that is traceable to national standards, has been certified by UKAS and is kept solely for calibration purposes. Copies of certificates that display a UKAS centre number and logo indicating calibration are the only proof that calibration to national standards has been attained, and must be held on site.
The PMIs are listed in the Table 17.4, according to their criticality.

Table 17.4 Examples of flow meters and their calibration

Risk level	High	Medium	Low
Accuracy	± 0.2 % of full instrument range range	± 1 % of full instrument range	>1 % of measuring range
Examples	Filling by flow meter	Feed flow Wastage flow	Effluent water
Recommended instruments	Electro magnetic flow meter	Electromagnetic flow meters	No recommendations
Calibration intervals	6 monthly	12 monthly	When practical
Calibration method	i. The Working Standards used for calibration must be traceable to national or international standards. ii. The Working Standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. The method of calibration must be according to international standards such as ISO 9000 and ISO 17025 and accreditation held for this method. iv. The person performing the calibration must be adequately trained, as required by ISO 10725.	i. The Working Standards used for calibration can be a local standard but must be traceable to national standards. ii. The Working Standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. Calibration may be performed by a person trained to at least level 3 in food safety and hygiene and who has received specific training.	No specific method required
Documentation	i. Records of calibration must include documentation that calibration of PMIs has been held up against a Working Standard in order to be valid. ii. Records of calibration must be kept for at least 2 years. iii. List instruments, as in Annex 1.	i. Records of calibration must be kept for at least 2 years. ii. All calibrated instruments, should be listed as in Annex 1.	No documentation required

If an inspection proves that the actual condition of certain PMIs dictate different intervals, then the interval can be adjusted accordingly. Any change in intervals must be documented with observations regarding condition and with nature of the change.

Conductivity

Conductivity measurement is used in CIP because the various cleaning solutions are more conductive than the water used for flushing and rinsing and it is a cost-effective way of monitoring the CIP steps. It is for instance very effective at detecting the interface between cleaning solutions and the product, which makes it possible for valves to switch at the right moment to reduce the interface between the two liquids and any resulting loss.

A **conductivity sensor** is an instrument used to measure the conductivity of a process stream. The conductivity is measured by applying a current between the two metal plates of the conductivity sensor.

A **conductivity transmitter** is a signal converter that converts a sensor or transducers signal into an output representative of the sensed conductivity. Conductivity transmitters are used in controlling conductivity processes by transmitting the signal from the sensor to a remote location. The

output of the transmitter can be transmitted to a control room or to another process device, such that the process can be controlled and monitored.

When calibrating conductivity measuring systems they are usually held up against a "Working Standard". A Working Standard is an instrument with an accuracy that is traceable to national standards, has been certified by UKAS and is kept solely for calibration purposes. Copies of certificates that display a UKAS centre number and logo indicating calibration are the only proof that calibration to national standards has been attained, and must be held on site. According to their criticality, the PMIs are listed in the Table 17.5.

If an inspection shows that the condition of certain PMIs exhibits different intervals, then the interval can be adjusted accordingly. Any change in intervals must be documented with observations regarding condition and with nature of the change.

Table 17.5 Examples of conductivity sensing systems and their calibration

Risk level	High	Medium	Low
Accuracy	± 2 % of expected reading on calibrated fluid	± 5 % of expected reading on calibrated fluid	>10 % of expected reading on calibrated fluid
Examples	White water and CIP control	None	None
Recommended instruments	CLD132 and other from reputable suppliers	No recommendations	No recommendations
Calibration intervals	6 monthly	12 monthly	When practical
Calibration method	i. The working standards used for calibration must be traceable to national or international standards. The working standards must be kept solely for calibration duties, and must never be used as spare instruments. ii. The method of calibration must be according to international standards such as ISO 9000 and ISO 17025 and accreditation held for this method. iii. The person performing the calibration must be adequately trained, as required by ISO 10725.	i. The Working Standards used for calibration can be a local standard but must be traceable to national standards. ii. The working standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. Calibration can be performed by an employee.	No specific method required
Documentation	i. Records of calibration must include documentation that calibration of PMIs has been held up against a Working Standard in order to be valid. ii. Records of calibration must be kept for at least 2 years. iii. All calibrated instruments, should be listed as in Annex 1.	i. Records of calibration must be kept for at least 2 years. ii. All calibrated instruments, should be listed as in Annex 1.	No documentation required

Level

Level measurement is used to measure the liquid quantity in tanks. If level measurement is inaccurate, it might cause a significant amount of product to be left in a tank, which then will go to waste.

A hydrostatic pressure sensor is often used for level measurement. This sensor measures the pressure applied by the liquid contained at the bottom of the tank, and relates this to a level of the contents. Other methods are by weighing scales or by ultrasonics.

A level transmitter is a signal converter that converts a sensor or transducers signal into an output representative of the sensed level. Level transmitters are used in controlling liquid levels in tanks by transmitting the signal from the sensor to a remote location. The output of the transmitter can be transmitted to a control room or to another process device, such that the process can be controlled and monitored.

When calibrating level measuring systems they are usually held up against a "Working Standard". A Working Standard is an instrument with an accuracy that is traceable to national standards, has been certified by UKAS and is kept solely for calibration purposes. Copies of certificates that display a UKAS centre number and logo indicating calibration are the only proof that calibration to national standards has been attained, and must be held on site.

According to their criticality, the PMIs are listed in Table 17.6. If an inspection proves that the actual condition of certain PMIs dictate different intervals, then the interval can be adjusted accordingly. Any change in intervals must be documented with observations regarding condition and with nature of the change.

Table 17.6 Examples of level sensing systems and their calibration

Risk level	High	Medium	Low
Accuracy	± 0.2 % of full tank volume	± 1 % of full tank volume	>1 % of full tank volume
Examples	None	Storage tanks CIP tanks	Storage tanks CIP tanks
Recommended instruments	No recommendations	Hydrostatic pressure sensor	No recommendations
Calibration intervals	6 monthly	12 monthly	When practical
Calibration method	i. The working standards used for calibration must be traceable to national or international standards. ii. The working standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. The method of calibration must be according to international standards such as ISO 9000 and ISO 17025 and accreditation held for this method. iv. The person performing the calibration must be adequately trained, as required by ISO 10725.	i. The Working Standards used for calibration can be a local standard but must be traceable to national standards. ii. The working standards must be kept solely for calibration duties, and must never be used as spare instruments. iii. Calibration can be performed by an employee.	No specific method required

Risk level	High	Medium	Low
Documentation	i. Records of calibration must include documentation that calibration of PMIs has been held up against a Working Standard in order to be valid. ii. Records of calibration must be kept for at least 2 years. iii. All calibrated instruments, should be listed as in Annex 1.	i. Records of calibration must be kept for at least 2 years. ii. All calibrated instruments, should be listed as the in Annex 1.	No documentation required

Weighing

Weighing scales are often used for verifying the filled amount in filling machines and mixing plants. They measure the weight of the product, and relate it to a product volume. Inaccurate weighing scales could result in lower volumes of product than legally required, being filled in the bottles.

When calibrating weighing scales they are usually held up against a "Working Standard". A Working Standard is a weight with an accuracy that is traceable to national standards, has been certified by UKAS and is kept solely for calibration purposes. Copies of certificates that display a UKAS centre number and logo indicating calibration are the only proof that calibration to national standards has been attained, and must be held on site. According to their criticality, the PMIs are listed in Table 17.7.

If an inspection proves that the actual condition of certain PMIs dictate different intervals, then the interval can be adjusted accordingly. Any change in intervals must be documented with observations regarding condition and with nature of the change.

Table 17.7 Examples of conductivity sensing systems and their calibration

Risk level	High	Medium	Low
Accuracy	± 0.1 % of measuring range	± 1 % of measuring range	>1 % of measuring range
Examples	Filling measurement	Storage tanks	None
Recommended instruments	Digital loading cells (HBM)	Digital loading cells	No recommendations
Calibration intervals	3 monthly	12 monthly	When practical
Calibration method	1. The working standards used for calibration must be traceable to national or international standards. 2. The working standards must be kept solely for calibration duties, and must never be used as spare. 3. The method of calibration must be according to international standards such as ISO 9000 and ISO 17025 and accreditation held for this method. 4. The person performing the calibration must be adequately trained, as required by ISO 10725.	i. - The Working Standards used for calibration can be a local standard but must be traceable to national standards. ii. The working standards must be kept solely for calibration duties, and must never be used as spare. iii. Calibration can be performed by an employee.	No specific method required

Risk level	High	Medium	Low
Documentation	1. - Records of calibration must include documentation that calibration of PMIs has been held up against a Working Standard in order to be valid. 2. Records of calibration must be kept for at least 2 years. 3. All calibrated instruments, should be listed as in Annex 1.	i. Records of calibration must be kept for at least 2 years. ii. All calibrated instruments, should be listed as the in Annex 1.	-No documentation required

Chart recorders

Charts are used to record the process parameters during the production run. Charts are kept as documentation that the values of the process parameters are within the legal requirements for food safety.

A chart recorder is an instrument used to record various process and electrical signals. The most traditional chart recorders record data on paper. The paper is passed under a pen and the pen is deflected in proportion to the signal. The result is a graph or chart of the data. Chart recorders are available in single or multichannel styles (single or multi-pen) and in various configurations.

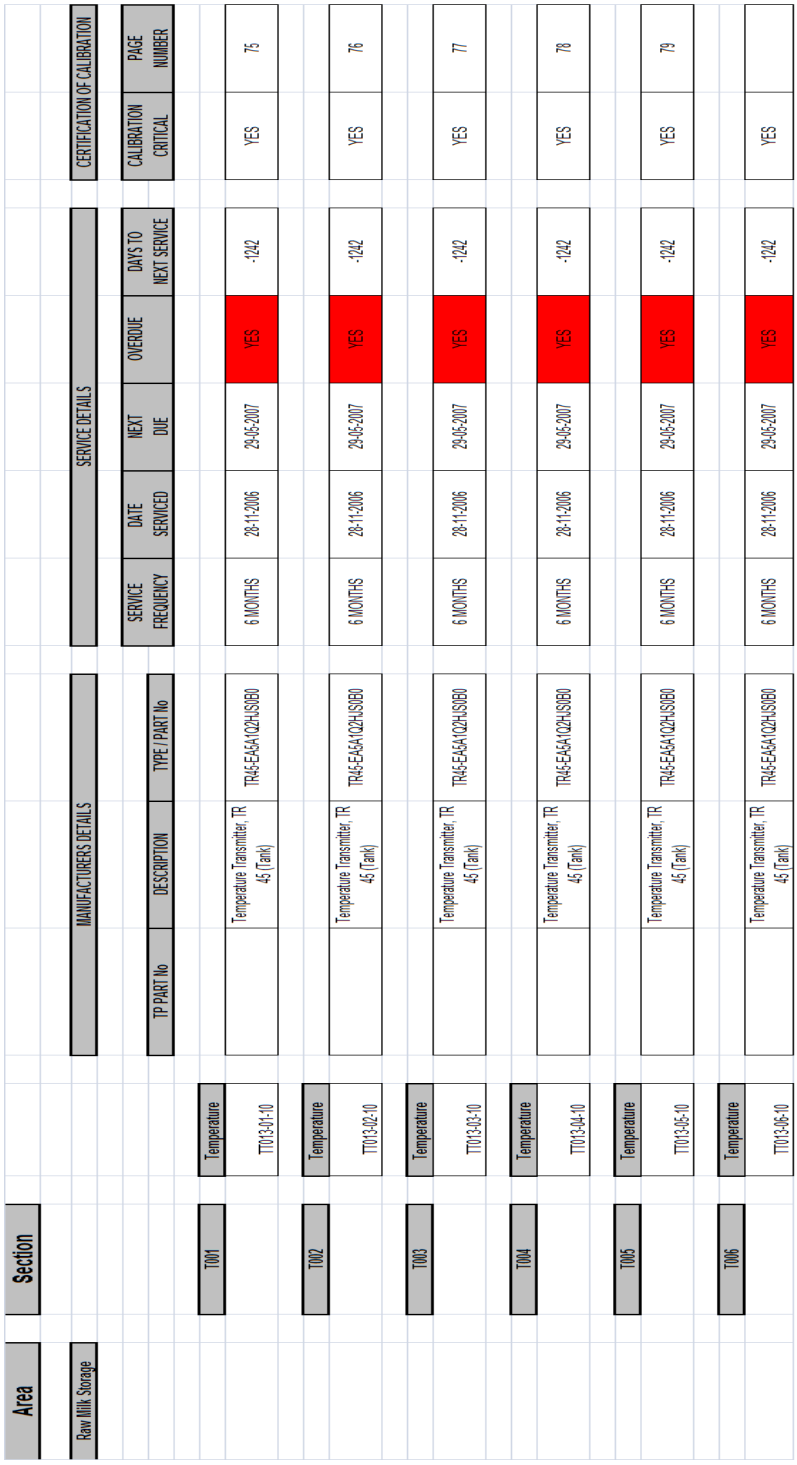
When validating chart recorders they are usually held up against a "Working Standard". A Working Standard is an instrument with an accuracy that is traceable to national standards, has been certified by UKAS and is kept solely for validation purposes. Copies of certificates that display a UKAS centre number and logo indicating calibration are the only proof that validation to national standards has been attained, and must be held on site. Paper charts must be set to within 5 minutes of a reference clock. All events must be marked on the chart to identify reasons.

General comments

ISO 17025 is the main standard used by testing and calibration laboratories. This specifies the general requirements for the competence to carry out tests and/or calibrations, including sampling. It covers testing and calibration performed using standard methods, non-standard methods, and laboratory-developed methods. The latest version is ISO 17025:2005.

Sign off and implementation

The implementation of this requirement will be managed by site processing and production managers executed by site engineering managers and supported by site managers, central functions and operational directors. An example of a schedule is given in Figure 17.1.



Area	Section	MANUFACTURERS DETAILS			SERVICE DETAILS				CERTIFICATION OF CALIBRATION	
		TP PART No	DESCRIPTION	TYPE / PART No	SERVICE FREQUENCY	DATE SERVICED	NEXT DUE	OVERDUE	DAYS TO NEXT SERVICE	CALIBRATION CRITICAL	PAGE NUMBER
Raw Milk Storage	T001	Temperature TT013-01-10	Temperature Transmitter, TR 45 (Tank)	TR45-EA5A1Q2HJS0IB0	6 MONTHS	28-11-2006	29-05-2007	YES	-1242	YES	75
	T002	Temperature TT013-02-10	Temperature Transmitter, TR 45 (Tank)	TR45-EA5A1Q2HJS0IB0	6 MONTHS	28-11-2006	29-05-2007	YES	-1242	YES	76
	T003	Temperature TT013-03-10	Temperature Transmitter, TR 45 (Tank)	TR45-EA5A1Q2HJS0IB0	6 MONTHS	28-11-2006	29-05-2007	YES	-1242	YES	77
	T004	Temperature TT013-04-10	Temperature Transmitter, TR 45 (Tank)	TR45-EA5A1Q2HJS0IB0	6 MONTHS	28-11-2006	29-05-2007	YES	-1242	YES	78
	T005	Temperature TT013-05-10	Temperature Transmitter, TR 45 (Tank)	TR45-EA5A1Q2HJS0IB0	6 MONTHS	28-11-2006	29-05-2007	YES	-1242	YES	79
	T006	Temperature TT013-06-10	Temperature Transmitter, TR 45 (Tank)	TR45-EA5A1Q2HJS0IB0	6 MONTHS	28-11-2006	29-05-2007	YES	-1242	YES	

Fig. 17.1 Example of a schedule for instrument recalibration

Maintenance of key processing plant

Purpose

This procedure defines minimum maintenance requirements for key processing plant with product contact in milk processing sites, e.g. separators, bactofuges, Alfast, Compomasters and homogenisers.

Requirements

Maintenance of key plant must be carried out according to the intervals in Table 17.8. Relevant testing of the plant, and verification of performance, must follow all maintenance.

After any service of separators or bactofuges, discharge volumes must be checked while running dry without hood flush, to ensure that performance is within specification.

In addition to the testing, processing plant operators must visually inspect the integrity of the key plant at regular intervals, report on condition and arrange for repairs as required.

Table 17.8 Required minimum intervals for maintenance

Plant	Intermediate service	Major service	Compulsory post service testing
Separator	6 months	12 months	Discharge and vibration
Bactofuge	6 months	12 months	Discharge and vibration
Alfast	N/A	12 months	Fat % must be within ± 0.75 % of target value as measured by FT-120 or equivalent, e.g. nominal 38 % cream should be 38.29 % ± 0.29 %
Alfast calibration	6 months	12 months	
CompoMaster	N/A	12 months	
CompoMaster calibration	6 months	12 months	
Homogeniser wet end	6 months	12 Months	Verification of homogenisation efficiency by microscope or by centrifugation with methyl blue
Homogeniser back end	N/A	12 Months	

Sign off and implementation

The implementation of this requirement will be managed by site engineering managers and supported by other site functions, central functions and operational directors.

Safety testing of plate heat exchangers and vessels

Purpose

This procedure is to define Product Safety Testing requirements for plate heat exchangers (PHEs) and vessels in milk processing sites.

Scope

All PHEs and tanks with product contact in milk processing sites.

Requirements

The following tests must take place according to the intervals in Table 17.9:

- Detection of leaks in any PHE with product contact
- Verification of holding time in holding tubes
- Calibration of related instruments
- Crack testing of product vessels
- Leak detection of pasteurisers and UHT plants needs to be on all surfaces with product contact. When an indication of leaking is found then a dye penetration test must follow with plate replacement and resealing.
- Test records must be kept for minimum of 3 years.

- In addition to the testing, the processing plant operators must visually inspect the integrity of PHEs and tanks at regular intervals, report on condition and arrange for repairs as required.

Table 17.9 Required intervals for testing

Type	Interval	Method
Level 4 Pasteurisers	36 months	Leak test by helium detection, saline/conductivity method or fluorescent dye
Non Level 4 Pasteurisers (finished product only)	12 months	Leak test by helium detection, saline/conductivity method or fluorescent dye
Other product contact heat exchangers	36 months	Leak test by helium detection, saline/conductivity method or fluorescent dye
UHT heat exchangers	6000 hours	Leak test by helium detection, saline/conductivity method or fluorescent dye
Holding Tubes	12 months	Holding time verification by approved method
Pasteuriser instrumentation	6 months	Calibration
Raw milk vessels	36 months	Crack testing by fluorescent dye
Rework vessels	36 months	Crack testing by fluorescent dye
Finished milk vessels	12 months	Crack testing by fluorescent dye
Sterile finished milk vessels	12 months	Crack testing by fluorescent dye

Sign off and implementation

The implementation of this requirement will be managed by site engineering managers and supported by other site functions, central functions and operational directors.

Valve and pump maintenance

This procedure is to define maintenance requirements for valves and pumps with product contact in all milk processing sites.

Valves and pumps must be maintained according to values in Table 17.10.

If an inspection proves that the actual condition of certain valves or pumps dictate different intervals, then the interval can be adjusted accordingly. Any change in intervals must be documented with observations regarding condition and with nature of the change.

The maintenance intervals for finished UHT and microfiltered milks as well as divert valves cannot in any circumstance be longer than the intervals indicated. Processing plant operators must inspect the integrity of product valves and pumps at regular intervals, report on condition and arrange for repairs as required.

Table 17.10 Required intervals for maintenance

	Interval (months)
CIP routing valves	36
Raw milk valves	36
Reclaim valves	24
Finished milk valves	12
Finished UHT cream or milk valves	6 (max limit)
Finished microfiltered milk valves	12 (max limit)
Finished cream valves	12
Divert valves	4 (max limit is 6)
Product pumps	24
Non-product pumps	At failure

Sign off and implementation

The implementation of this requirement must be managed by site engineering managers and supported by site managers, central functions and operational directors.

Appendix

List of abbreviations

%	Percent (assume compositions to be on a mass:mass basis unless stated otherwise)
ADMI	American Dried Milks Institute (now superseded by ADPI)
ADPI	American Dairy Products Institute
ALP	Alkaline phosphatase
AMS	Automated milking system
ATU	Allyl thiourea
A_w	Water activity
BCMS	British Cattle Movement Service
BOD	Biochemical oxygen demand
CAP	Common agricultural policy
CCP	Critical control point
CF	Concentration factor
cfu	Colony forming unit
CIP	Cleaning-in-place
CMP	Caseinomacropeptide (aka glycomacropeptide)
COD	Chemical oxygen demand
CTMP	
Defra	Department for Environment, Food and Rural Affairs
EC	European Community
ED	Electrodialysis
EM	Evaporated milk
ESL	Extended shelf life
EU	European Union
FDM	Fat in dry matter
FTIR	Fourier transform infra-red
GMP	Good manufacturing practice
HACCP	Hazard analysis critical control point
HDPE	High density polyethylene
HHT	High heat treatment (more severe than pasteurisation)
HTST	High-temperature-short-time
IDF	International Dairy Federation
IDFA	International Dairy Foods Association
L	Litre

LDPE	Low density polyethylene
MAFF	Ministry of Agriculture, Fisheries and Food (superseded by Defra)
MF	Microfiltration
MFF	Microfiltration fractionation
MFGM	Milk fat globule membrane
MMB	Milk Marketing Board
MNFS	Moisture in non-fat substance
MRL	Maximum residual level
MWCO	Molecular weight cut-off
MVR	Mechanical vapour compression
NACEPE	National Association of Creamery Proprietors
NF	Nanofiltration
NPN	Non protein nitrogen
NTU	Nephelometric turbidity unit
P*	Pasteurisation index
Pa	Pascal
PA	Polyamide
PAA	Peracetic acid
PES	Polyethersulphone
PET	Polyethylene terephthalate
PHE	Plate heat exchanger
PMI	Process monitoring instruments
PP	Polypropylene
PS	Polystyrene
Pt100	Platinum resistance sensor
PVC	Polyvinyl chloride
RO	Reverse osmosis
rpm	Revolutions per minute
SCC	Somatic cell count
SCM	Sweetened condensed milk
SFP	Single farm payment
S/M	Salt in moisture
SW	Spiral wound
TCMP	Trichloro methyl pyridene
TMP	Transmembrane pressure
TN	Total nitrogen
TOC	Total organic carbon
TS	Total solids

TVR	Thermal vapour compression
UF	Ultrafiltration
UHT	Ultra high temperature
UK	United Kingdom of Great Britain and Northern Ireland
VCF	Volume concentration factor
WPN	Whey protein nitrogen