Dairy technology

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BEFEKTETÉS A JÖVŐBE

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1. Production of milk

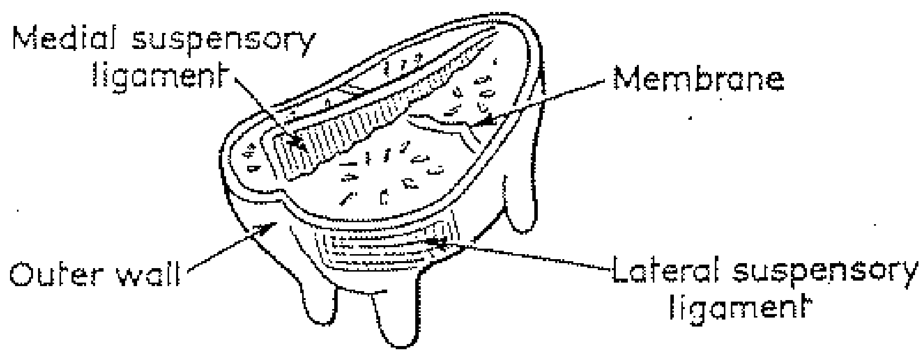
Milk is the only food contains every essential nutriment for young mammal during the first period of its life, after birth (energy, vitamins, water, etc.). Milk also contains antibodies which protect the young mammal against infection. A calf needs only about 1000 litres of milk for growth, and most of cows are able to produce much more.

Enormous changes have explored since man took the cow into his service. Selective and intensive breeding has resulted in dairy cows which yield more than 6 500 litres of milk per a lactation, i.e. more than six times as much as the primitive cow. Some cows can produce above 10 000 litres.
Before a cow can start to produce milk she must have calved first. Heifers reach sexual maturity at the age of seven or eight months but are not usually fertilized until they are 15 - 18 months old. The gestation period is approximately 285 days, varying according to the cow breed, so a heifer produces her first calf at the age of about 2.5 years. Remarkably hormonal changes need for the starting of milk secretion. Prolactin is an essential peptide hormone is associated with lactation and milk secretion in the udder. It stimulates the mammary glands to produce milk (lactation): Increased serum concentrations of prolactin during gestation cause enlargement of the mammary glands of the udder and prepare the production of milk via a special hormonal regulation. Parallel with this, the high levels of progesterone during pregnancy suppress the production of milk. Milk production normally starts when the levels of progesterone remarkably fall at the end of gestation, actually some days before calving.

Secretion of milk

The milk is secreted in the cow's udder - a hemi-spherical organ divided into right and left halves by a crease. Each half is divided into quarters by a shallower transverse crease. Each quarter has one teat with its own separate mammary gland. A sectional view of the udder is shown in Fig. 1.

The udder is organized of glandular tissue, what is built up from milk producing cells. It is encased in muscular tissue, which gives cohesion to the body of the udder and protects it against injury from mechanical impacts (knocks and blows).
The glandular tissue contains a very large number (about 2 billion) of tiny bladders, in other words “alveoli”. The actual milk-producing cells are located on the inner walls of the alveoli, which occur in groups of between 8 and 120. Capillaries leading from the alveoli converge into progressively larger milk ducts which lead to a cavity above the teat. This cavity, known as the cistern of the udder, can hold up to 400 ml of milk.



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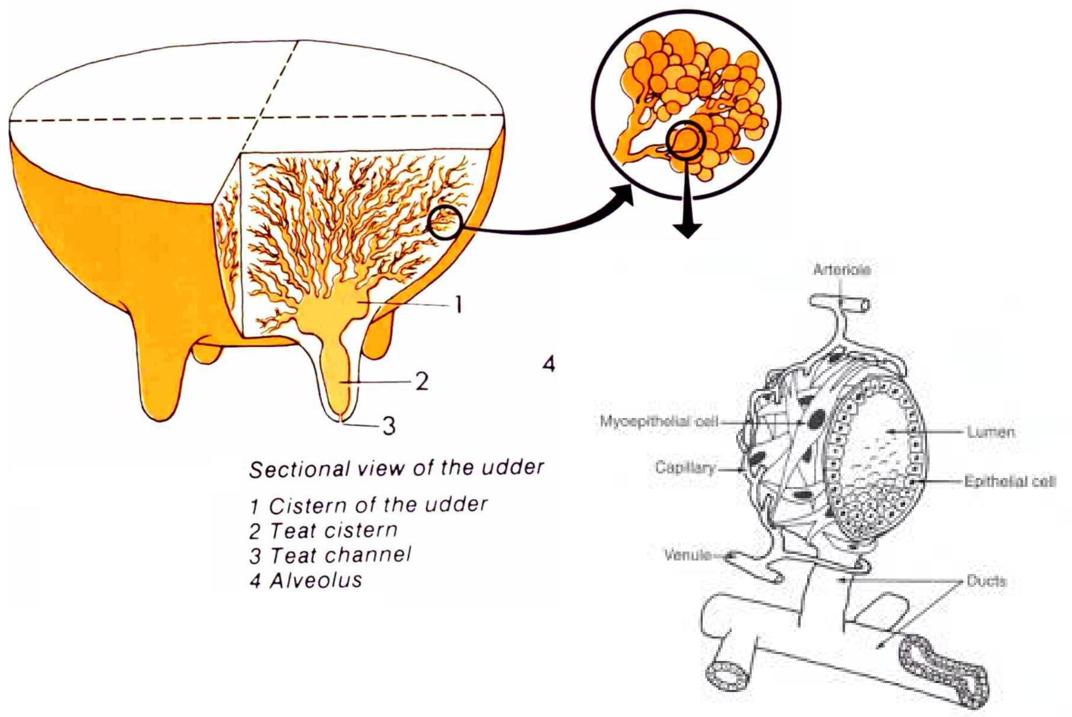
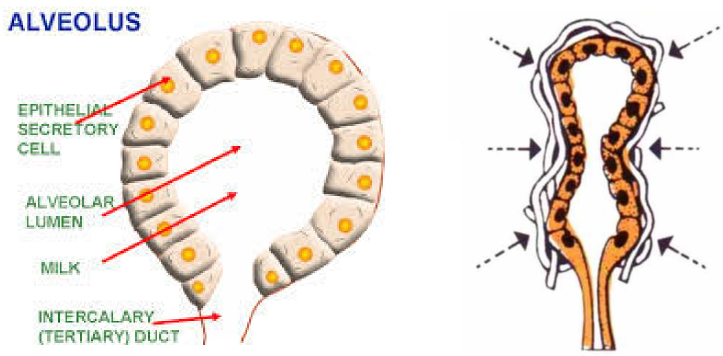


Figure 1. Structure of the udder

The cistern of the udder has an extension reaching down into the teat; this is the teat cistern. At the end of the teat, there is a 1 - 1.5 cm long channel. Between milkings the channel is closed by a sphincter muscle which prevents milk from leaking out and bacteria from entering the udder.



Milk production by alveolus cells

Expresson of milk from alveolus

Figure 2. Expression of milk from alveolus

The whole udder is laced with blood and Lymph vessels. These bring nutrient-rich blood from the heart to the udder, where it is distributed by capillaries surrounding the alveoli. In this way the milk-producing cells are furnished with the necessary nutrients for the secretion of milk. "Spent" blood is carried away by the capillaries to veins and returned to the heart. The blood stream through the udder is around 90 000 litres a day. It suggests between 400 and 800 litres of blood result one litre of milk.

As the alveoli secrete milk their internal pressure rises. If the cow is not milked, secretion of milk stops when the pressure reaches a certain limit. Increase of pressure forces a small quantity of milk out into the larger ducts and down into the cistern. Most of the milk in the udder, however, is contained in the alveoli and the fine capillaries in the alveolar area. These capillaries are so fine that milk cannot flow through them on its own accord. It must be pressed out of the alveoli and through the capillaries into the larger ducts. Muscle-like cells surrounding each alveolus perform this duty during milking, see Fig.2.

The lactation cycles

Secretion of milk in the cow's udder begins some days before calving, therefore the calf can begin to feed immediately after birth. The cow then continues to give milk for about 260-300 days. This period is named as lactation or lactation period.
One to two months after calving, the cow can be serviced again. During the lactation period the milk production decreases after a peak, and six to nine months after the birth of the calf the milk production ceases. New lactation cycle begins after the birth of the calf.
A cow is productive for a 5 years period – in average - but in the intensive breeding systems cows are scrapped after 2 or 3 lactations. The one of its reasons is that the milk production decreases after the first or mainly the second lactation period.

Milking

A hormone called oxytocin must be released in to the cow's bloodstream in order to start the emptying of the udder. This hormone is secreted and stored in the hypophysis. When the cow is prepared for milking by the right stimuli, a signal is sent to the hypophysis which then releases its store of oxytocin into the bloodstream.
In the primitive cow the stimulus is provided by the calf's attempts to suck on the teat. The oxytocin is released when the cow feels the calf sucking. A modern dairy cow has no calf but is conditioned to react to other stimuli, i.e. to the sounds, smells and sensations associated with milking.
The oxytocin begins to take effect about one minute after preparation has begun and causes the muscle-like cells to compress the alveoli. This generates pressure in the udder and can be felt with the hand known as the letdown reflex. The pressure forces the milk down into the teat cistern, from which it is sucked by the teat cup of a milking machine or pressed out by the fingers during hand milking.
The effect of the letdown reflex regularly fades away as the oxytocin is diluted and decomposed in the bloodstream, disappearing after 5 - 8 minutes. Milking should therefore be completed within this period of time. If the milking procedure is prolonged in an attempt to "strip" the cow, this places an unnecessary strain upon the udder; the cow becomes irritated and may become difficult to milk.
If there is no time to milk the cow while the letdown reflex is in progress, it is best to omit milking. After 20 - 30 minutes the hypophysis will have secreted a fresh charge of oxytocin and the cow can then be prepared for milking in the usual way.

Hand milking

On many farms all over the world milking is still done by hand in the same way as it has been done for thousands of years. However, today hand milking is more efficient as all the mechanisms that influences milking are known. Cows are usually milked by the same people every day, and are quickly stimulated to let down just by hearing the familiar sounds of the preparations for milking.

Milking begins when the cow responds with the letdown reflex. The first milk from the teats is rejected as it contains large amounts of bacteria. By a careful, visual check of this first milk it is possible to notice any changes that may indicate that the cow is ill.

Two diagonally opposed quarters are milked at a time: one hand presses the milk out of the teat cistern, after which the pressure is relaxed to allow more milk to run down into the teat from the cistern of the udder. At the same time milk is pressed out of the other teat, so that the two teats are milked alternately. When two quarters have been stripped this way, the milker then proceeds to milk the other two until the whole udder is empty.

The milk is collected in pails and poured through a strainer, to remove coarse impurities, into a churn holding 30 - 50 litres. The churns are then chilled and stored at a low temperature to await transport to the dairy. Immersion or spray chillers are normally used for cooling.

Machine milking

On medium to large farms with large herds, the usual practise is to milk cows by machine. The milking machine sucks the milk out of the teat by vacuum. The milking equipment consists of a vacuum pump, a vacuum vessel which also serves as a milk collecting pail, teat cups connected by hoses to the vacuum vessel, and a pulsator which alternately applies vacuum and atmospheric pressure to the teat cups.

The teat cup unit consists of a teat cup of stainless steel containing an inner tube of rubber, called the teat cup liner. The inside of the liner, in contact with the teat, is subjected to a constant vacuum of about 0.5 bar (50% vacuum) during milking. The phases of milking are shown in Fig 3.

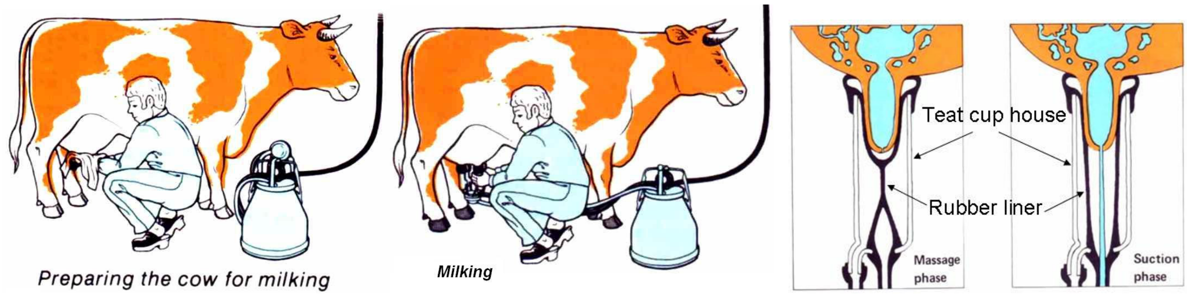
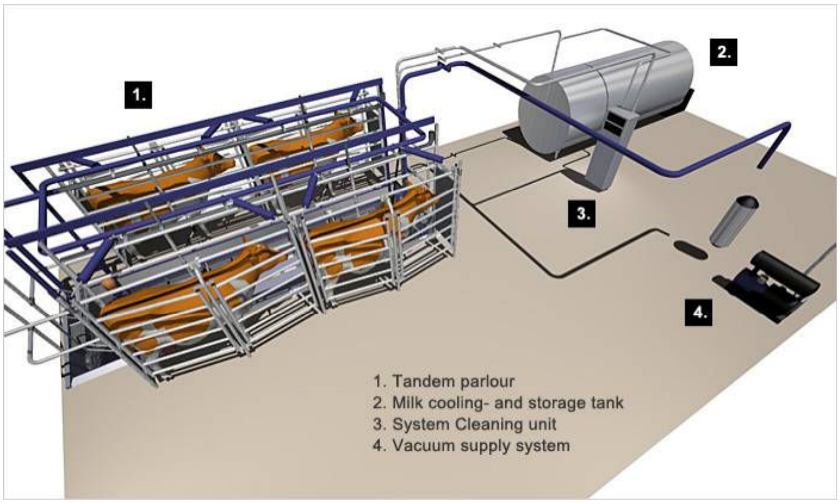


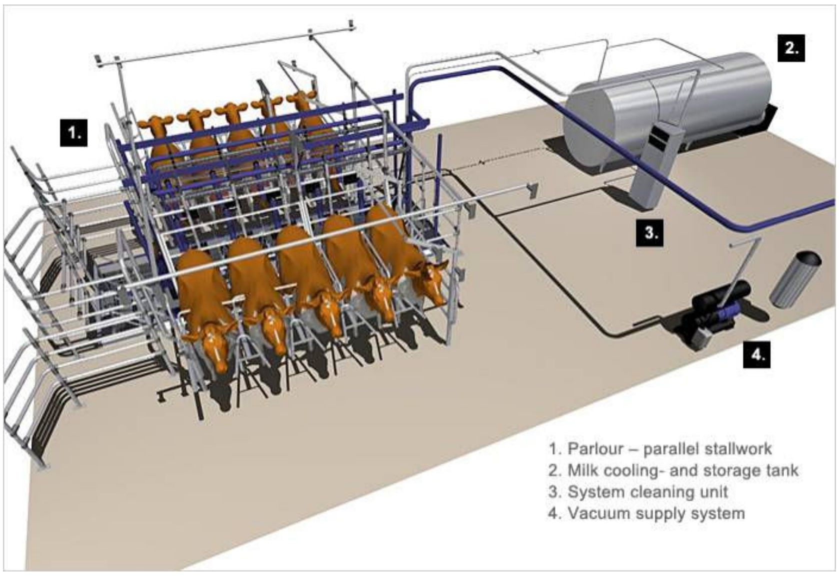
Figure 3. The phases of machine milking

The pressure in the pulsation chamber (between the liner and teat cup) is regularly alternated, by the pulsator, between 0.5 bar during the suction phase and atmospheric pressure during the massage phase. The result is that milk is sucked from the teat cistern during the suction phase. During the massage phase the teat cup liner is pressed together to stop milk suction, allowing new milk to run down into the teat cistern from the udder cistern. This is followed by another suction phase, and so on.

Relaxation of the teat during the massage phase is necessary to avoid accumulation of blood and fluid in the teat, which is painful to the cow and will cause her to stop letting down. The pulsator alternates between the suction and massage phases 40 to 60 times a minute. Four teat cups are attached to a manifold, called the milk claw, and are placed on the cow's teats by suction. During mil king, suction is alternately applied to one pair of diagonally opposed teats and then to the other pair. The milk is drawn from the teats to the vacuum vessel. An automatic shut-off valve operates to prevent dirt from being drawn into the system if a teat cup should fall off during milking. After the cow has been milked, the milk pail (vacuum vessel) is taken to a milk room where it is emptied into a churn or a special milk tank for chilling.

To eliminate the heavy and time-consuming work of carrying filled pails to the milk room, a pipeline system may be installed for direct transport of the milk to the milk room by means of vacuum. Such systems are widely employed on large farms. In this way the milk can be conveyed in a closed system straight from the cow to a collecting tank in the milk room, which is a great advantage from the bacteriological point of view. It is however important that the pipeline system is designed to avoid air from being picked up and to handle the milk gently.
Fig. 4 present some type of parlour layout.





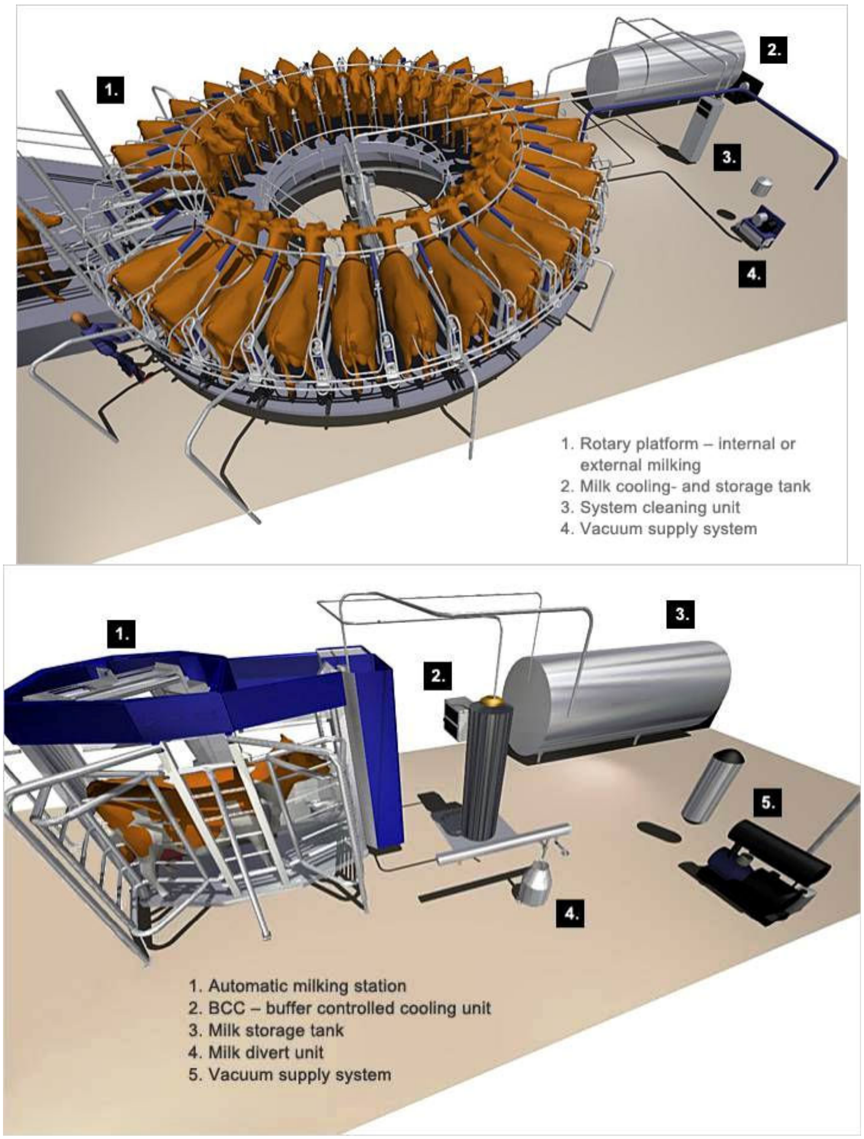


Figure 4. Parlour layouts

Chilling milk on the farm

Milk leaves the udder at a temperature of about 37°C. Fresh milk from a healthy cow is practically free from bacteria, but must be protected against infection as soon as it leaves the udder. Microorganisms capable of spoiling the milk are everywhere - on the udder, on the milker's hands, on airborne dust particles and water droplets, on straw and chaff, on the cow's hair and in the soil. Milk contaminated in this way must be filtered.

Careful attention must be paid to hygiene in order to produce milk of high bacteriological quality. However, despite all precautions, it is impossible to, completely exclude bacteria from milk. Milk is in fact an excellent growth medium for bacteria - it contains all the nutrients they need. So as soon as bacteria get into the milk they start to multiply. On the other hand the milk leaving the teats contains certain original bactericids which protect the milk against the microorganism actions during the first period. It also takes some time for infecting micro-organisms to adapt to the new medium before they can begin to grow.

Unless the milk is chilled, it will quickly be destroyed by the microorganisms, which thrive and multiply most vigorously at temperatures around 37°C. Milk should therefore be chilled quickly to about 4°C immediately after it leaves the cow. At this temperature the level of activity of micro-organisms is very low. But the bacteria will start to multiply again if the temperature is allowed to rise during storage. It is therefore important to keep the milk well chilled.
Under certain circumstances, e.g. when water and/or electricity is not available on the farm or when the milk quantities are too small to justify the investment needed on the farm, cooperative milk collecting centres should be established.

Farm cooling equipment

Spray or immersion coolers are used on farms which deliver milk to the dairy in churns. In the spray cooler, circulating chilled water is sprayed on the outsides of the churns to keep the milk cool. The immersion cooler consists of a coil which is lowered into the churn. Chilled water is circulated through the coil to keep the milk at the required temperature.
Where milking machines are used, the milk is collected in bulk in special farm tanks. These come in a variety of sizes with built-in cooling equipment, designed to guarantee chilling to a specified temperature within a specified time. These tanks are also often equipped for automatic cleaning to ensure a uniform, high standard of hygiene (Fig. 5).

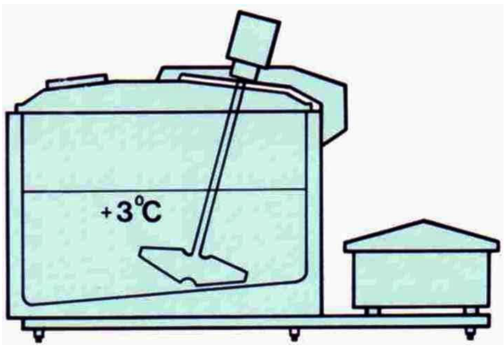
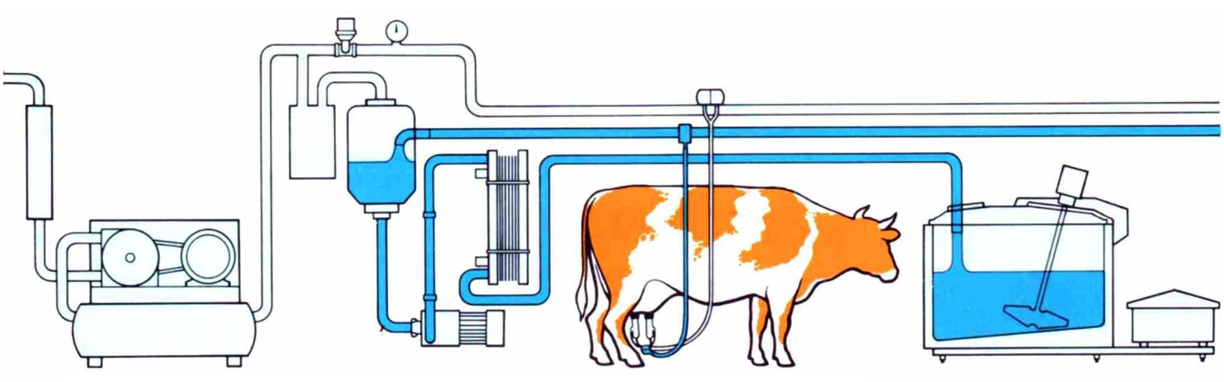


Figure 5. Bulk milk cooling tank with agitator and chilling unit

On very large farms and in collecting centres, where large volumes of milk (more than 5 000 litres) must be chilled quickly from 37 to 4 °C, the cooling equipment in the bulk tanks is inadequate. In these cases it is used simply to maintain the required storage temperature; the actual cooling is carried out in heat exchangers in the pipeline (Fig. 6)



The milk run - a closed system from cow to storage tank contains a plate heat exchanger (cooler)

Figure 6. Closed milking and milk manipulator system

2. The chemistry of milk

The principal constituents of milk are water, fat, proteins, lactose (a type of sugar) and minerals (salts). Milk also contains trace amounts of other substances such as pigments, enzymes, vitamins, phospholipids (substances with fatlike properties), and gases.
The residue left when water and gases are removed is called the *dry solids* (DS) or *total solids* content of the milk.
Milk is a very complex product and raw material as well. In order to describe the various constituents of milk and how they are affected by the various stages of treatment in the dairy, it is necessary to understand basic knowledge about colloidics and this complex emulsion.

Different distribution types

Milk consists of about 87% water and 13% dry substance. The dry substance is dispersed or dissolved in the water. Depending on the amount or size of the solids there are different distribution types, see Table 1.

Table 1. Size of dispersion's particles of the different distribution types

Distribution type	**Particle size (nm)***
Coarse dispersion (suspension or emulsion)	50-100
Fine dispersion	1-100
Genuine solution	0.1-1
Ionic solution	-1

(*: 1 nm = 10^{-9} m)

Dispersions

Dispersion is obtained when particles of a substance are distributed - dispersed - in a liquid. There are two kinds of dispersions: suspension and emulsion.
A suspension consists of solid particles dispersed in a liquid. The force of gravity acts on the suspended particles, causing them either to sink to the bottom or float to the surface. The finer the particles, the more stable the suspension.
An emulsion is a mixture of two liquids which do not dissolve in each other. It normally consists of an aqueous (water) phase and an oil phase. The oil phase may be dispersed in the form of droplets in the water phase (o/w emulsion) or vice versa (w/o emulsion). Cream is an o/w emulsion, whereas butter is a water/oleic emulsion.
Oil is water repellent, i.e. hydrophobic, whereas water is attracted to water, i.e. hydrophilic. The area of the interface between the phases in an emulsion is very large. For example, one millilitre of oil can be broken up into a dispersion of more than 15 000 000 000 droplets 5 μm (0.005 mm) in diameter, with a total surface area of 1.2 square metres.
To keep an emulsion stable, the dispersed liquid droplets must be prevented from coalescing into larger droplets. This can be attained by adding an emulsifying agent with both hydrophil and hydrophob qualities, e.g. mayonnaise. The hydrophobic part of the emulgator is bound to the oil droplet surfaces while the hydrophil part is turned towards the water giving the oil droplets hydrophilic properties. This prevents the oil droplets from coalescing.
Milk contains several natural emulsifying agents. The fat droplets in milk, for example, are surrounded by a membrane of lipoprotein only 5 nm (0.000005 mm) thick acting as emulsifying agent. Consequently milk is a stable system from this point of view.

Colloid solutions (fine dispersions)

In a colloid solution, the particles consist of larger groups of molecules that float freely. The proteins in milk are present as colloid solutions.

The main difference between a colloid solution and a suspension lies in the size of the particles; those in a colloid solution are much smaller than in a suspension. As a result, colloid solutions are usually stable.
Colloids can be precipitated by a change in temperature, by an increase in acidity or by enzymes. When this happens, the colloid is said to gel. Gelling is also called coagulation or flocculation. If the gel is solid and cohesive, it is called a coagulum.

Pure (real) solutions

Matter which, when mixed with water or other liquids, forms pure solutions, is divided into:

- non-ionic solutions. When lactose is dissolved in water, no important changes will occur in the molecular structure of the lactose.
- ionic solutions. When common salt is dissolved in water, cations (Na^+) and anions (Cl^-) will be dispersed in the water, forming an electrolyte.

Composition of milk

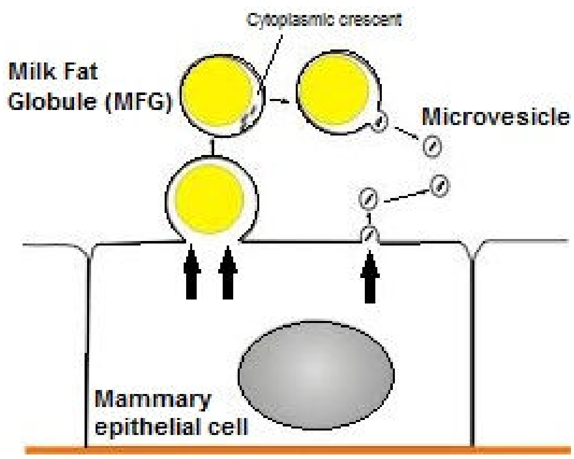
The quantities of the various main constituents of milk can vary considerably between cows of different breeds and between individual cows of the same breed. Therefore only limit values can be stated for the variations. The figures in Table 2 are simply examples.

Table 2. Composition of cow milk

Main constituent	Limits of variation %	Mean value %
Water	85.5-89.5	87.5
Total solids	10.4-14.5	13.0
Fat	2.5-6.0	3.9
Proteins	2.9-5.0	3.4
Lactose	3.6-5.5	4.8
Minerals	0.6-0.9	0.8

Beside total solids, the term: Solids non fat (SNF) is used in discussing the composition of milk. SNF is the total solids content less the fat content.

Milk fat



If milk is left to stand, a layer of cream will form on the surface. The cream differs considerably in appearance from the bottom layer of skim milk. Under the microscope, cream can be seen to consist of a large quantity of spheres, globules of varying size, floating freely in the milk. Each globule is surrounded by a thin “skin”, actually a special membrane.

These tiny spheres are fat globules, and the skin consists of protein (mucous membrane) and phospholipids. As will be seen later, the skin has an important function; it protects the fat from being broken down by enzymes present in the milk.
The fat globules have got the largest particle size in

milk. Their diameters range from 0.1 to 20 μm (1 μm = 0.001 mm). The average size is 3 - 4 μm (in cow milk), and there are 3 000 - 4 000 million fat globules in a millilitre of whole milk. The size of the fat globules has a significant effect on the yield of dairy processes and the quality of some products. The larger the globules, the easier they are to separate from the skim milk.

Chemical structure of milk fat

Ali fats belong to a group of chemical substances called esters, which are compounds of alcohols and acids. Milk fat is a mixture of different fatty-acid esters called triglycerides, which are compounds of an alcohol called glycerol and various fatty acids. Fatty acids make up about 90% of milk fat.
A fatty-acid molecule is composed of a hydrocarbon chain and a carboxyl group (formula COOH). In saturated fatty acids the carbon atoms are linked together in a chain by single bonds, while in unsaturated fatty acids there are one or more double bonds in the hydrocarbon chain. Each glycerol molecule can bind three fatty-acid molecules, and as the three need not necessarily be of the same kind, the number of different glycerides in milk is very large. Table 3 lists the most important fatty acids in milk fat triglycerides.

Table 3. Main fatty acids in cow milk

Fatty acid	% of total Fatty acid content	Melting point (°C)
Saturated	**63.7 (mean)**	
Butyric acid (	3.0-6.2	-8.0
Caproic acid	1.3-3.8	-4.0
Caprylic acid	0.8-2.0	+16.0
Capric acid	1.8-3.8	+31.0
Lauric acid	2.0-5.0	+44.0
Myristic acid	7.8-14.0	+54.0
Palmitic acid	22.0-41.90	+63.0
Stearic acid	7.0-13.6	+70.0
Unsaturated	**36.3 (mean)**	
Oleic acid	20.0-36.0	+16.0
Linoleic acid (CLA)	0.8-5.2 (1.2-2.5)	-5.0 ---
Linolenic acid	0.3-2.9	-12.0

Melting point of fat

Table 3 shows that the four most abundant fatty acids in milk are myristic, palmitic, stearic and oleic acids. The first three are solid and the last is liquid at room temperature. As the represented figures indicate, the relative amounts of the different fatty acids can vary in a wide range, mainly due to the different feeding regime. This variation affects the hardness of the fat. Fat with a high content of high-melting fatty acids, such as palmitic acid, will be hard; on the other hand, fat with a high content of low-melting oleic acid results soft butter.
To know the detailed fatty acid composition of milk fat can be important only for scientific reason but the main characteristics, indices (as melting point or ratio of unsaturated FA) can be useful in the dairy processing (see the butter making).

Iodine value

The most important and most widely used of these indices is the *iodine value* (IV), which shows the percentage of iodine that the fat can bind. Iodine is taken up by the double bonds of the unsaturated fatty acids. Since oleic acid is by far the most abundant of the unsaturated fatty acids, which are liquid at room temperature, the IV is largely a measure of the oleic-acid content and thereby of the softness

of the fat.
The IV of butterfat normally varies between 24 and 46. The variations are determined by what the cows eat. Green pasture in the summer promotes a high content of oleic acid (and other unsaturated acids), so that summer milk fat is soft (high IV). Certain fodder concentrates, such as sunflower cake, linseed cake, rapeseed also result softer fat, while types of fodder such as coconut and palm oil cake and root vegetable tops lead to harder fat. It is therefore possible to influence the consistency of milk fat (butter) by choosing a suitable diet for the cows. For the optimum consistency of butter, IV should be between 32 and 37.

Proteins in milk

Proteins are an essential part of our diet. The proteins we eat are broken down into simpler compounds in the digestive system and in the liver. These compounds are then conveyed to the cells of the body where they are used as construction material for building the body's own protein. The great majority of the chemical reactions that occur in the organism are controlled by certain active proteins, the enzymes.
Proteins are giant molecules built up of smaller units, the amino acids. A protein molecule consists of one or more interlinked chains of amino acids, where the amino acids are arranged in a specific order. A protein molecule usually contains around one or two hundred linked amino acids, but both smaller and much larger numbers are known to constitute a protein molecule.

Amino acids

Although the total number of amino acids known amounts to hundreds, only 18 of them are found in the milk proteins. Some of the 18 amino acids are present in one form or other of chemical modification, making the number of amino acids in milk proteins slightly larger.
The form and the order of the amino acids in the protein molecule determine the nature of the protein exactly. Any change of amino acids regarding the type or the place in the molecular chain will result in a protein with different properties.

As the possible number of combinations of 18 amino acids in a chain containing 100 - 200 amino acids is almost unlimited, the number of proteins with different properties will also be almost unlimited.
The characteristic feature of amino acids is that they contain both a slightly basic amino group ($-NH_2$) and a slightly acid carboxyl group (-COOH). These groups are connected to a hydrocarbon chain.
If the hydrocarbon chain is short, i.e. contains from 1 to 3 carbon atoms, the water-attracting properties of the basic and the acid groups will dominate and the whole amino acid will attract water and be easily dissolved in water. Such an amino acid is named hydrophilic (water loving).

On the other hand, if the hydrocarbon chain is long, i.e. if the carbon number is more than 3 and the chain does not contain hydrophilic substituents, the properties of the hydrocarbon chain will dominate. A long hydrocarbon chain will repel water and make the amino acid less soluble or compatible with water. Such an amino acid is called hydrophobic (dislikes water) or, preferably, less hydrophilic.
If there are certain substituents in the hydrocarbon chain, such as hydroxyl groups (-OH) or amino groups ($-NH_2$), the hydrophobic properties will be modified towards more hydrophilic. If hydrophobic amino acids are dominating within one part of a protein molecule, that part will have hydrophobic properties. An aggregation of hydrophilic amino acids in another part of the molecule will in analogy give that part hydrophilic properties. A protein molecule may therefore be either hydrophilic, hydrophobic, intermediate or locally hydrophilic and hydrophobic.

Table 4. Essential amino acid in human, camel, cow, goat and sheep milk (mg amino acid/ g total amino acid).(Sabahelkheir, Fat and Hassan, 2012)

EAA /Species	Human	Camel	Cow	Goat	Sheep
Lysine	20.2[b]	12.8[d]	20.8[c]	26.3[d]	18.7[a]
Methionine	11.3[b]	9.1[c]	9.6[c]	3.5[d]	9.9[a]
Phenylalanine	69.0[b]	54.5[c]	71,9[c]	62.1[d]	67.2[a]
Threonine	59.7[b]	53.2[c]	81.7[c]	68.9[d]	59.9[d]
Tryptophan	NT	NT	NT	NT	NT
Histidine	40.4[b]	27.7[c]	38.8[c]	31.1[d]	41.6[a]
Asparagines	NT	NT	NT	NT	NT

*Mean values having different letters within column are significantly difference at P ≤ 0.05.

Some milk proteins demonstrate very great differences within the molecules with regard to water compatibility, and some very important properties of the proteins depend on such differences. Hydroxyl groups in the chain of some amino acids in casein may be esterified with phosphoric acid. Such groups enable casein to bind calcium ions or colloidal calcium hydroxyphosphate, forming strong bridges between or within the molecules.

Isoelectric point of proteins

The amino acids in milk proteins carry an electric charge which is determined by the pH of the milk. At neutral pH (pH = 7), some amino acids, such as Aspargic and Glutamic acid, are negatively charged, while others, such as Lysine and Arginine, are positively charged. If a protein contains more acid than basic amino acids at neutral pH it is negatively charged, and vice versa.
When the pH of milk is changed by the addition of an acid, the charge distribution of the proteins is also changed. At a pH value where the positive charge of a protein is equal to the negative charge, i.e. where the numbers of NH_3^+ and COO^- groups are equal, the net total charge of the protein is zero. This pH is called the isoelectric point of the protein. (Casein: 4.6 pH)

The milk protein classes

Milk contains many hundred protein types, most of them in very small amounts. According to their abundance, their chemical or physical properties or their biological functions, the proteins can be classified in various ways. The old way of classing the milk proteins into casein, albumin and globulin has given way to a more adequate classification system. Table 5 shows a list of the main milk proteins according to a modern system. In order to simplify matters, minor protein groups are excluded.

Table 5 Sharing of protein fractions in cow milk (g/kg milk protein)

	Amount	
Protein	**Average**	**Range**
α_s-Casein (s_1+s_2)	434	350-630
β-Casein	242	190-350
κ-Casein	107	80-150
γ-Casein	20	10-30
Total casein	**803**	**760-860**
Serum albumin	9	5-13

β-Lactoglobulin	96	70-140
α-Lactalbumin	37	20-50
Immunoglobulins	22	10-40
Proteose peptone	33	20-60
Total serum proteins	**197**	**140-240**
Other miscellaneous	27	
Membrane proteins	20	

Whey protein is a term often used as a synonym for milk-serum proteins, but it should be reserved for the proteins in whey from the cheese making process. In addition to milk-serum proteins the whey protein also contains fragments of casein molecules. Some of the milk-serum proteins are also present in lower concentration than in the original milk. This is due to heat denaturation during the pasteurization of the milk prior to cheese making.
The three main groups of proteins in milk are distinguished by their widely different behaviour and form of existence. The caseins are easily precipitated from milk in a variety of ways, while the serum proteins usually remain in solution. The fat-globule membrane proteins adhere, as the name implies, to the surface of the fat globules and are only released by mechanical action, e.g. by churning cream into butter.

Casein

Casein is a group name for the dominant class of proteins in milk, the caseins. As in all proteins the caseins easily form polymers containing several identical or different types of molecules. Due to the abundance of ionizable groups and hydrophobic and hydrophilic sites in the casein molecule the molecular polymers formed by the caseins are very special. The polymers are built up of hundreds and thousands of individual molecules and form a colloidal solution, which can be observed in the skim milk because of its whitish-blue appearance. These molecular complexes are known as casein micelles. Such micelles may be as large as 0.4 micrometers, but can only be seen under an electron microscope.

Casein micelles

The three subgroups of casein, the αs-casein, the *κ-casein* and the β-casein are all heterogenous and consist of 2 - 8 genetic variants. Genetic variants of a molecule differ from each other only by a few amino acids. The three subgroups have in common the fact that some amino acids are esterified to phosphoric acid. The phosphoric acid binds calcium and magnesium and some of the complex salts to form bonds between and within molecules.
αs-casein has a molecule, one end of which is hydrophobic and the other comparatively hydrophilic. β-casein has a molecule with two ends that are fairly hydrophobic compared to the middle part of the molecule. κ-casein has a molecule, where one part is rich in long-chain amino acids while another part is very rich in carbohydrates, bonded to the hydrocarbon chain, which makes the first part of the molecule hydrophobic while the second becomes hydrophilic.

At temperatures above 20 °C there is a strong tendency, due to the hydrophobic ends of the β-casein molecules, to associate end to end and form long chains, which are the "backbones" in the micelle. The hydrophobic joints in the chain will then attract the hydrophobic part of the s-casein molecules and form a chain with "rosettes", see Fig. 7.

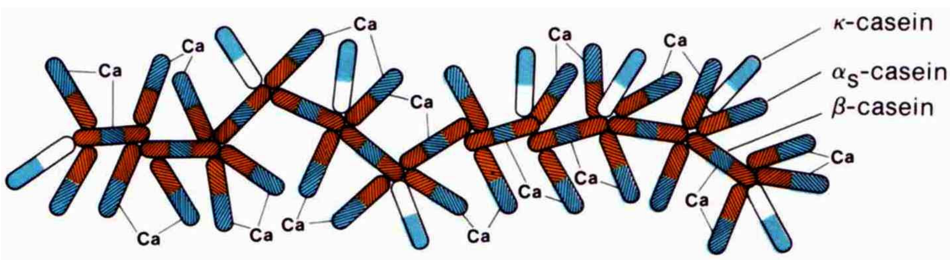


Figure 7. Main milk casein fractions attach to each other and form molecular clusters exposing strongly hydrophilic part to the water (called: “rosettes”)

This chain will fold into globules, primary micelles as shown in Fig. 8. κ-casein will attach its hydrophobic end to corresponding exposed sites on the surface of the primary micelles, directing its hydrophilic end towards the open water. By further association with primary micelles, partly with the aid of calcium salts and esterified phosphoric acid, larger micelles are formed. Such micelles are illustrated in Fig. 8.

Calcium salts of αs-casein and β-casein are almost insoluble in water, while those of -casein are easily soluble. Due to the dominating localisation of κ-casein to the surface of the micelles, the solubility of calcium-κ-caseinate will dominate the insolubility of the other two salts in the micelles, and the whole micelle will be soluble as a colloid.
If the hydrophilic sites on the surfaces of such micelles are split, e.g. by rennet, the micelles will lose their solubility and start to aggregate and form casein curd. In an intact micelle there is a balance between sites attracting each other and sites repelling each other. Water molecules held by the hydrophilic sites of κ-casein form an important part of this balance. If the hydrophilic sites are removed the water will start to leave the structure.

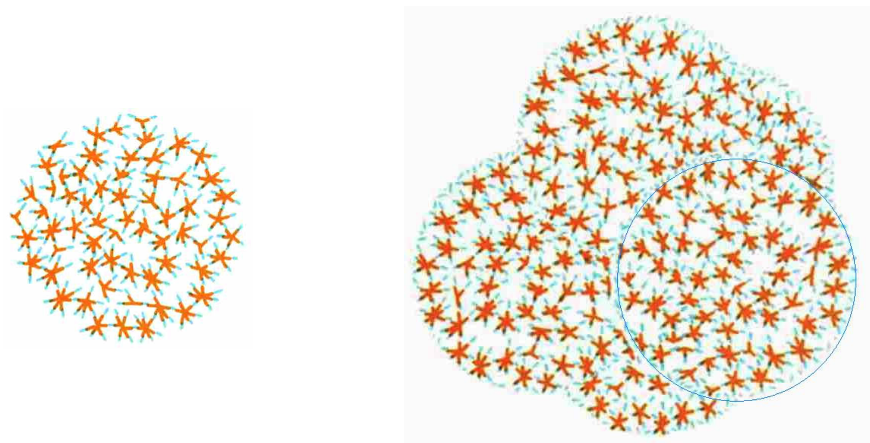


Figure 8. Casein submicelles attach to large casein micelles

This gives the attracting forces room to act. New bonds are formed, both of the salt type, where calcium is active, and of the hydrophobic type. These bonds will then enhance the expulsion of water and the structure will finally collapse into a dense curd.
The micelles are adversely affected by a low temperature. At temperatures close to freezing point the β-casein chains start to dissociate and the calcium hydroxyphosphate leaves the micelle structure, where it existed in colloidal form, and becomes a solution. These changes make the milk less suitable for cheese making, due to longer renneting time and a softer curd. Storing the milk for some minutes at temperatures above 500C will, at least partially, restore the original properties of the milk.

Precipitation of casein
One characteristic property of casein is its ability to precipitate. Due to the complex nature of the casein molecules, and that of the micelles formed from them, the precipitation can be caused by many different agents. It should be observed that there is a great difference in the optimum precipitation conditions between casein in micellar form and in non-micellar form, e.g. as sodium caseinate. The following dissertation refers mainly to the precipitation of micellar casein.

Precipitation by acid
The pH will drop if an acid is added to milk or if acid-producing bacteria are allowed to grow in milk. This will change the environment of the casein micelles in two ways. First colloidal calcium hydroxyphosphate, present in the milk, will dissolve and form ionized calcium, which will penetrate the micelle structure and create strong internal calcium bonds. Secondly the pH of the solution will approach, and pass, the isoelectric points of the individual casein species.
Both methods of action will initiate a change within the micelles, starting with the size of the micelles growing through aggregation and ending with a more or less dense coagulum. Depending on the final value of the pH, this coagulum contains casein in the casein salt form or casein in isoelectric state or both.
The isoelectric points of the casein components are dependent on the ions of other kinds present in the solution. Theoretical values, valid under certain conditions, are pH 5.1 to 5.3. In salt solutions, similar to the condition of milk, the range for optimum precipitation is pH 4.5 to 4.9. A practical value for precipitation of casein from milk is pH 4.7. If a large excess of acid is added to a certain coagulum the casein will redissolve, forming a salt with the acid. If hydrochloric acid is used, the solution will contain casein hydrochloride, partly dissociated into ions.
The pH of cultured milk products is usually in the range 3.9 to 4.5, which is on the acid side of the isoelectric points. In the manufacture of casein from skim milk by the addition of sulphuric or hydrochloric acid the pH chosen is often 4.6.

Precipitation by enzymes
The amino-acid chain forming the K-casein molecule consists of 169 amino acids. From an enzymatic point bf view the link between amino acids 105 (phenylalanin) and 106 (methionin) is particularly weak. Most proteolytic enzymes will attack this link and split the chain. One part formed contains amino acids 106 to 148 and, together with them, ali carbohydrates of the K-casein that gave the molecule its hydrophilic properties. That part of the K-casein molecule is called the macropeptide and is released in the cheese whey in cheese making. The remaining part of the K-casein, consisting of amino acids 1 to 105, is fairly insoluble and remains together with O's- and ,B-casein in the cheese curd. That part is called para-K-casein. Formerly, all the curd was said to consist of para-casein.
The formation of the curd is due to the sudden removal of the hydrophilic ma cropeptide and the unbalance in intermolecular forces caused thereby. Bonds between hydrophobic sites start to develop and are enforced by calcium bonds which develop as the water molecules in the micelles start to leave the structure. This process is usually referred to as the phase of coagulation and syneresis.
The splitting of the link 105 - 106 in the K-casein molecule is often call ed the primary phase of the rennet action, while the phase of coagulation and syneresis is referred to as the secondary phase. There is also a tertial phase of rennet action, where the rennet attacks the casein components in a more general way. This occurs during cheese ripening.

The velocity of the three phases is mainly determined by pH and temperature. In addition to this the secondary phase is greatly affected by the calcium ion concentration and by the condition of the micelles with reg ard to absence or presence of denatured milk serum proteins on the surface of the micelles.

Milk-serum proteins
If the casein is removed from skim milk by some precipitation method, such as the addition of mineral acid, there remains in solution in the liquid a group of proteins which may be called milk-serum

proteins. As long as they are not denatured by heat they are not precipitated at their isoelectric points. Polyelectrolytes, however, like carboxymethylcellulose usually precipitate them. In technical processes, where milk serum proteins are recovered, use is often made of su ch substances or of a combination of heat and pH adjustment.

When milk is heated, parts of the milk-serum proteins form denatured complexes with casein, decreasing the ability of the casein to be attacked by rennet and to bind calcium. Cheese curd from milk, heated to a high temperature, will not release whey as ordinary cheese curd does, due to lesser number of casein bridges within and between the casein molecules.
Milk-serum proteins in general, and a-lactalbumin in particular, have very high nutritional values. Their amino-acid composition is very close to that which is regarded as a biological optimum. Whey protein preparates are widely used in the food industry.

α-lactalbumin
This protein may be considered to be the typical milk-serum protein. It is present in milk from ali mammals and plays a significant role in the udder during the synthesis of lactose.

β-lactoglobulin
This protein is unique for cloven hoofed animals and is the major milk serum protein component in milk from cows. If milk is heated to over 60 °C a series of reactions is initiated - where the reactivity of the sulphur-amino acid of β-lactoglobulin plays a dominant part. Sulphur bridges start to form between the β-lactoglobulin molecules, between one β-lactoglobulin molecule and a K-casein molecule and between β-lactoglobulin and α-lactalbumin. At high temperatures sulphur containing compounds such as hydrogen sulphide are gradually released. Such sulphur-containing compounds are responsible for the "cooked" flavour of heat treated milk.

Immunoglobulins and related minor proteins
This protein group is extremely heterogeneous and few of its members are studied more closely. In the future many substances of importance will probably be isolated on a commercial scale from milk serum or whey. Lactoferrin and lactoperoxidase are substances of possible use in medicine and the food industry.

Membrane proteins
Membrane proteins are a group of proteins, forming a protective skin around the fat globules. Their properties are similar to those of skin and hair, but range in consistency between soft and jelly-like in some of the membrane proteins to rather tough and firm in others. Some of the proteins contain lipid residues and are called lipoproteins. The lipids and the hydrophobic amino acids of those proteins make the molecules direct their hydrophobic sites towards the fat surface, while the less hydrophobic parts are oriented towards the water.
Weak hydrophobic membrane proteins attack these protein layers in the same way, forming a gradient of hydrophobia from the fat surface on to the water.
The gradient of hydrophobia in such a membrane makes it an ideal place for adsorbtion for molecules of all degrees of hydrophobia. Especially phospholipids and lipolytic enzymes are adsorbed within the membrane structure. No reactions occur between the enzymes and their substrate as long as the structure is intact. As soon as the structure is destroyed the enzymes have an opportunity to find their substrate and start reactions.

An example of enzymatic reaction is the lipolytic liberation of fatty acids when milk has been pumped cold with a faulty pump or after homogenization of cold milk without pasteurization following immediately. The fatty acids and some other products of this enzymatic reaction will cause "rancid" flavour to the product.

Denatured proteins

As long as proteins exist in an environment with a temperature and pH within their limits of tolerance, they retain their biological functions. But if they are heated to temperatures above a certain maximum their structure is altered. They are said to be denatured. The same thing happens if proteins are exposed to acids or bases, to radiation or to via lent agitation. The proteins are denatured and lose their original solubility.

When proteins are denatured, their biological activity ceases. Enzymes, a class of proteins whose function is to catalyze reactions, lose this ability when denatured. The reason is that certain bands in the molecule are broken, changing the structure of the protein. It has recently been shown that denatured proteins can revert to their original state, with restoration of their biological functions.

In many cases, however, denaturation is irreversible. The proteins in a boiled egg, for example, cannot be restored to the raw state. Irreversible denaturation is called coagulation.

Enzymes in milk

Enzymes are a group of proteins produced by living organisms. They have the ability to trigger chemical reactions and to affect the course and speed of such reactions. Enzymes do this without being consumed. They are therefore sometimes called biocatalysts. An enzyme probably takes part in a reaction, but is released again when it has completed its job.

The action of enzymes is specific; each type of enzyme only catalyzes one type of reaction.

Two factors which strongly influence enzymatic action are temperature and pH. As a rule enzymes are most active in an optimum temperature range between 25 and 50 °C. The activity drops if the temperature is increased beyond optimum, ceasing altogether somewhere between 50 and 120 °C. At these temperatures the enzymes are more or less completely destroyed (inactivated). The temperature of inactivation varies from one type of enzyme to another - a fact which has been widely utilized for the purpose of determining the degree of pasteurization of milk. Enzymes also have their optimum pH ranges; some function best in acid solutions, others in an alkaline environment.

The enzymes in milk come either from the cow's udder or from bacteria. The former are normal constituents of milk and are called *original/ enzymes.* The latter, *bacteria/ enzymes* vary in type and abundance according to the nature and size of the bacterial population. Several of the enzymes in milk are utilized for quality testing and control. Among the more important ones are peroxidase, catalase, phosphatase and lipase.

Peroxidase

Peroxidase transfers oxygen from hydrogen peroxide (H_20_2) to other readily oxidizable substances. This enzyme is inactivated if the milk is heated to 80 °C for a few seconds, a fact which can be used to prove the presence or absence of peroxidase in milk and thereby check whether or not a pasteurization temperature above 80 °C has been reached. This test is called Storch's peroxidase test.

Catalase

Gatalase splits hydrogen peroxide into water and free oxygen. By determining the amount of oxygen that the enzyme can release in milk, it is possible to estimate the catalase content of the milk and learn whether or not the milk has come from an animal with a healthy udder. Milk from diseased udders has a high catalase content, while fresh milk from a healthy udder contains only an insignificant amount. There are however many bacteria which produce this kind of enzyme. Catalase is destroyed by ordinary HTST pasteurization (75 °C for 60 seconds).

Phosphatase

Phosphatase has the property of being able to split certain phosphoric-acid esters into phosphoric acid and the corresponding alcohols. The presence of phosphatase in milk can be detected by adding a phosphoric-acid ester and a reagent that changes colour when it reacts with the liberated alcohol. A change in colour reveals that the milk contains phosphatase. Phosphatase is destroyed by HTST pasteurization, so the phosphatase test can be used to determine whether the pasteurization

temperature has actually been attained. The routine test used in dairies is called the *phosphatase test* according to Sharer.
The phosphatase test should preferably be performed immediately after the heat treatment. Failing that, the milk must be chilled to below + 5 °C and kept at that temperature until analyzed. The analysis should be carried out the same day, otherwise a phenomenon known as reactivation may occur, i.e. an inactivated enzyme becomes active again and gives a positive test reading. Cream is particularly susceptible where this is concerned.

Lipase
Lipase splits fat into glycerol and free fatty acids. Excess free fatty acids in milk and milk products result in a rancid taste. The action of this enzyme seems, in most cases, to be very weak, though the milk from certain cows may show strong lipase activity. The quantity of lipase in milk is believed to increase towards the end of the lactation cycle. Lipase is, to a great extent, inactivated by HTST pasteurization, but higher temperatures are required for total inactivation. Many micro-organisms produce lipase. This can cause serious problems as the enzyme is very resistant to heat.

Lactose
Lactose is a sugar, and belongs to the group of organic chemical com pounds called *carbohydrates.*
Carbohydrates are the most important energy source in our diet. Bread and potatoes, for example, are rich in carbohydrates, and provide a reservoir of nourishment. They break down into high energy compounds which can take part in all biochemical reactions, where they provide the necessary energy. Carbohydrates also supply material for the synthesis of some important chemical compounds in the body. They are present in muscles as muscle glycogen and in the liver as liver glycogen. Blood sugar is also composed of carbohydrates.
Glycogen is an example of a carbohydrate with a very large molecule. Other examples are starch and cellulose. Such composite hydrocarbons are called polysaccharides and have giant molecules made up of many glucose molecules. In glycogen and starch the molecules are often branched, while in cellulose they are in the form of long, straight chains.

Disaccharides composed of two types of sugar molecules. The molecules of sucrose (ordinary cane or beet sugar) consist of two simple sugars (monosaccharides), fructose and glucose. Lactose (milk sugar) is also a disaccharide, with a molecule containing monosaccharide glucose and galactose. The lactose content of milk varies between 3.6 and 5.5%. What happens when lactose is attacked by lactic acid bacteria? These bacteria contain an enzyme called lactase which attacks lactose, splitting its molecules into glucose and galactose.
Other enzymes from the lactic-acid bacteria then attack the glucose and galactose, converting them into various acids of which lactic acid is the most important. This is what happens when milk goes sour, i.e. fermentation of lactose to lactic acid. Other micro-organisms in the milk generate other breakdown products.

If milk is heated to a high temperature, and is kept at that temperature, it turns brown and acquires a caramel taste. This process is called caramellization and is the result of a chemical reaction between lactose and proteins, the so called Maillard reaction.
Lactose is water soluble, occurring as a molecular solution in milk. In cheese making most of the lactose remains dissolved in the whey. Evaporation of whey in the manufacture of whey cheese increases the lactose concentration further. Lactose is not as sweet as other sugars; it is 30 times less sweet than cane sugar, for example.

Vitamins in milk

Vitamins are organic substances which occur in very small concentrations in both plants and animals. They are essential to normal life processes. The chemical composition of vitamins is usually very complex, but that of most vitamins is now known. The various vitamins are designated by capital letters, sometimes followed by numerical subscripts, e.g. A, B, and B_2.

Milk contains many vitamins. Among the best known are A, B" B_2' C and D. Vitamins A and Dare soluble in fat, or fat solvents, while the others are soluble in water.

Table 4 lists the amounts of the different vitamins in a litre of market milk and the daily vitamin requirement of an adult person. The Table shows that milk is a good source of vitamins. Lack of vitamins can result in deficiency diseases.

Table 4. Vitamins in milk

Vitamin	RDI, mg	% of RDI in 0.3 litre milk
A	1.3	46
B1 Thiamin	1.4	32
B2 Riboflavin	1.7	104
B6 Piridoxin	2.0	25
B12 Kobalamine	0.0004	113
Pantothenic acid	8.0	45
C	60.0	30
D	0.0025	32
E	10.0	11
Biotin (B7)	0.2	18

RDI: Recomended Daily Intake (for one adult/day)

Minerals or salts in milk

Milk contains a number of minerals. The total concentration is less than 1 %. Mineral salts occur in solution in milk serum or in casein compounds. The most important salts are those of calcium, sodium, potassium and magnesium. They occur as phosphates, chlorides, citrates and caseinates. Potassium and calcium salts are the most abundant in normal milk. The amounts of salts present are not constant. Towards the end of lactation, and even more so in the case of udder disease, the sodium chloride content increases and gives the milk a salty taste, while the amounts of other salts are correspondingly reduced.

Other constituents of milk

Milk always contains *white blood corpuscles* (leucocytes). The content is low in milk from a healthy udder, but increases if the udder is diseased - usually in proportion to the severity of the disease. Milk usually also contains *dissolved gases.* These consist mostly of carbon dioxide, nitrogen and oxygen.

3. Physical properties of milk

Appearance

The opacity of milk is due to its content of suspended particles of fat, proteins and certain minerals. The colour varies from white to yellow according to the colouration of the fat. Skim milk is more transparent, with a slightly bluish tinge.

Density
The *density* of milk normally varies between 1.028 and 1.034 g/ml, depending on the composition. Milk is therefore only slightly denser than water (1.0).

Freezing point
The *freezing point* of milk varies between -0.54 and -0.59 °C, depending on the content of lactose, proteins and minerals. The presence of these substances in water lowers the freezing point. A higher concentration would result in an even lower freezing point.

pH
Normal milk is very slightly acid, with a *pH of* 6.6-6.7. Phenolphthalein is used as an indicator to determine the *titratable* acidity of milk. Although phenolphthalein changes colour at a fairly low level of alkalinity (approx. pH 9), it takes quite a heavy dose of base to increase the pH of milk to that level. This is because milk contains buffering substances (phosphates, carbonates, citrates and proteins) which can emit hydrogen ions at the same rate as hydroxide ions are added with the base, neutralizing most of the added base without any significant change in the pH.
The acidity of milk can be defined as the number of millilitres of 0.1 M (molar) sodium hydroxide (NaOH) required for titration of 100 ml of milk, diluted with twice that amount of distilled water, and with phenolphthalein as the indicator. Molarity is an expression of the concentration of a solution. Acidity measured by this method is expressed in Thörner degrees (°Th), or Soxhlet Henkel degree (°SH). Normal, healthy milk has an acidity of 15 - 18 ° Th or 6.8 - 7.2 °SH. The acidity is higher in milk where lactic-acid bacteria have been allowed to develop, 90 - 110 °Th or 35-40 °SH in cultured sour milk.

Colostrum (raw milk)
The first milk that a cow produces after calving is called colostrum, or raw milk. It differs greatly from norm al milk in composition and properties. One highly distinctive characteristic is the high content of β-lactoglobulin, globulin and albumin. This results coagulating in colostrum, when it heated. Colostrum also contains antibodies which protect the calf from infection until its own immunity system has been established. Colostrum has a yellowish to brownish-yellow colour, a peculiar smell and a rather salty taste. The content of catalase and peroxidase is high. Four to five days after calving the cow begins to produce milk of normal composition, which can be mixed with other milk.

4. Collection and reception of milk

The milk is brought from the farm, or collecting centre, to the dairy for processing. Ali kinds of receptacles have been used, and are still in use, throughout the whole world, from 2 - 3 litres calabashes and pottery to modern bulk-cooling farm tanks for thousands of litres of milk.
Formerly, when dairies were small, collection was confined to nearby farms. The micro-organisms in the milk could be kept under control with a minimum of chilling, as the distances were short and the milk was collected daily.
Today the trend is towards progressively larger dairy units. The demand is for increased production without reduction in the quality of the finished product. Milk must be brought from farther away and this means that daily collection is generally out of the question. Nowadays collection usually takes place every other day, but the interval can often be three days and sometimes even four.

Keeping the milk cool

The milk should be chilled to below + 4 °C immediately after milking and be kept at this temperature all the way to the dairy.

If the cold chain is broken somewhere along the way, e.g. during transportation, the micro-organisms in the milk will start to multiply. This will result in the development of various metabolic products and enzymes. Subsequent chilling will arrest this development, but the damage has already been done. The bacteria count is higher and the milk contains substances that will affect the quality of the end product.

Design of farm dairy premises

The first steps in preserving the quality of the milk must be taken at the farm. Milking conditions must be as hygienic as possible; the milking system designed to avoid aeration, the cooling equipment correctly dimensioned.

To meet the hygienic requirements, dairy farms have special rooms for refrigerated storage. Bulk-cooling tanks are also becoming more common. These tanks, with a capacity of 250 to 10 000 litres, are fitted with an agitator and cooling equipment to meet certain stipulations - for example that all the milk in the tank should be chilled to below +4 °C within 2 hours of milking.

Larger farms, producing large quantities of milk, often install separate coolers for chilling the milk before it arrives in the tank. This saves mixing warm milk from the cow with the already chilled contents of the tank. A plant of this type is shown in Fig. 6.

The dairy room should also contain equipment for cleaning and disinfecting the utensils, pipe system and bulk cooling tank.

Delivery at the dairy

The raw milk arrives at the dairy in churns or in insulated road tankers, the latter being used only in combination with bulk cooling tanks at the farm. The requirements are the same for both methods the milk must be kept well chilled and free from air and treated as gently as possible. For example, churns and tanks should be well filled in order to prevent the milk from sloshing around in the container.

Churn collection

Milk is transported in churns of various sizes, the most common being of 30 or 50 litres capacity. The churns are taken from the farm to the roadside. This should be done just before the arrival of the collecting lorry, see Fig. 3. The churns should be protected from the sun by a tarpaulin or a shelter.

Milk collecting centres should be established in certain regions where there is no road to the dairy farm, when water and/or electricity are not available on the farm or when the milk quantities are too small to justify investment in cooling facilities. The centres can be organized in different ways and in accordance with the prevailing situation. The farmers have several alternatives. Uncooled milk in churns or cooled milk in insulated tanks can be delivered at certain road junctions, directly to tankers. Uncooled milk can also be delivered in churns to centrally placed cooling stations. Another alternative is that neighbouring farmers deliver their uncooled milk in churns to a larger farm.

The churn-collecting lorry follows a carefully planned schedule so that it always arrives at each collection point at the same time. After having been loaded onto the platform of the lorry the churns should always be covered with a tarpaulin for protection against the sun and dust. The lorry returns to the dairy as soon as the churns have been collected from all the farms on its route.

Each farm usually has a code number which is stamped on the churns. It is used by the dairy when calculating how much money the farmer should be paid.

Milk from diseased cows must not be supplied to the dairy together with milk from healthy animals. Milk from stock treated with antibiotics must be kept separate from other milk. Such milk cannot be used for products based on bacteria cultures, as the antibiotic strain will kill the bacteria. This applies to cultured milk products, cheese and butter etc.. Minute amounts of milk containing antibiotics can render enormous quantities of otherwise suitable milk unusable.

Bulk collection

When collecting milk by tanker it must be possible to drive all the way to the farm dairy room. The loading hose from the tanker is connected to the outlet valve on the farm cooling tank, see Fig. 5. The tanker is usually fitted with a flow meter and pump so that the volume is automatically registered. Otherwise the volume is measured by recording the level difference which, for the size of the tank in question, represents a certain volume. In many cases the tanker is equipped with a deaerator.
Pumping is stopped as soon as the cooling tank has been emptied. This prevents air from being mixed into the milk. The tank of the bulk collection vehicle is divided into a number of compartments in order to prevent the milk from sloshing around during transportation. Each compartment is filled in turn, and when the tanker has completed its scheduled round it delivers the milk to the dairy.

Testing milk for quality

Milk from sick animals and milk which contains antibiotics or sediment must not be accepted by the dairy. Even traces of antibiotics in milk can render it unsuitable for the manufacture of products which are acidified by the addition of bacteria cultures, e.g. yoghurt, cheese, etc.

Normally only a general assessment of the milk quality is made at the farm. The composition and hygienic quality is usually first determined in a number of tests on arrival at the dairy. The outcome of some of these tests has a direct bearing on the money paid to the farmer. The following are the most common tests carried out on milk supplies.

Taste and smell
In the case of bulk collection, the driver takes a sample of the milk at the farm for testing at the dairy. Churn collected milk is sampled at the churn reception department. Milk that deviates in taste and smell from normal milk receives a lower quality rating. This affects the payment to the producer. Milk with significant deviations in taste and smell should be rejected by the dairy.

Cleaning checks
The inside surfaces of farm tanks and churns are carefully inspected. Any milk residue is evidence of inefficient cleaning and will result in a deduction in accordance with a quality payment scheme.

Sediment tests
This only applies to churns. A sample is taken with a pipette from the bottom of a churn and is then passed through a filter. A quality deduction is made if visible impurities are retained by the filter.

Hygiene or Resazurin Tests
The bacteria content of the milk is a measure of the hygienic quality. The Resazurin Tests are used frequently. Resazurin is a blue dye which becomes colourless when it is chemically reduced by the removal of oxygen. When it is added to the milk sample, the metabolic activity of the bacteria present has the effect of changing the colour of the dye at a rate which bears a direct relationship to the number of bacteria in the sample.
Two hygiene tests use this principle. One is a quick-screening test, which may form the basis for the rejection of a bad churn supply. If the sample starts to change shade immediately, the consignment is considered unfit for human consumption.
The other test is a routine test and involves storage of the sample in a refrigerator overnight, before a Resazurin solution is added. The sample is then incubated in a water bath and held at 37.5 °C for two hours. It have to noticed that Resazurin test is not used officially in countries where the microbiological quality of raw milk is very good or countries have strict raw milk classification system. But it usable for estimate the microbiological quality of milk, of course.

Somatic cell count
A large number (more than 500 000/ml of milk) of somatic cells in the milk indicates that the cows are suffering from udder diseases. The cell content is determined by means of specially designed and

precise particle counters (Somacount, Coulter counter, Fossomatic, etc.) using in the official classification but there are some simpler methods for rough estimate e.g. CMT (California Masti-Test), or mobile instrument based on the determination of conductivity of milk.

Bacteria count

A simplified form of bacteria count can also be used in order to assess the bacteria content. In this, the Leesment method, the bacteria are cultivated at 30 °C for 72 hours in a 0.001 ml milk sample with a nutritive substrate. The bacteria count is determined by means of a special screen or in a Bürker chamber wit microscope. But this method needs much time. Flow cytometcic method is used for official and fast Somatic Cell count determination (SCC).

Protein content

Many dairies pay the farmers according to the protein content of the milk. This is analysed by means of instruments operating with infrared or near infrared rays (or with ultrasound). Up to 300 analyses/hour can be performed.

Fat content

Various methods can be used to determine the butterfat content. The Gerber or Röser-Gottlieb test based on the destruction of sample is the most widely used method for whole milk in the practice in a dairy firm. But the IR or NIR instruments are more precise and faster.

Freezing point

Many dairies check the freezing point of the milk in order to discover whether or not it has been diluted with water. Milk of normal composition has a freezing point of -0.54 to -0.59 °C. The freezing point will rise if water is added to the milk. Special instruments are used for this check.

Milk reception

Dairies have special reception departments to handle the milk brought in from the farms. At the reception the first measure is to determine the quantity of the milk. The quantity is recorded and entered into the weighing system that the dairy uses to weigh the intake and compare it with the finished production.
The quantity of the intake can be measured by volume or by weight.

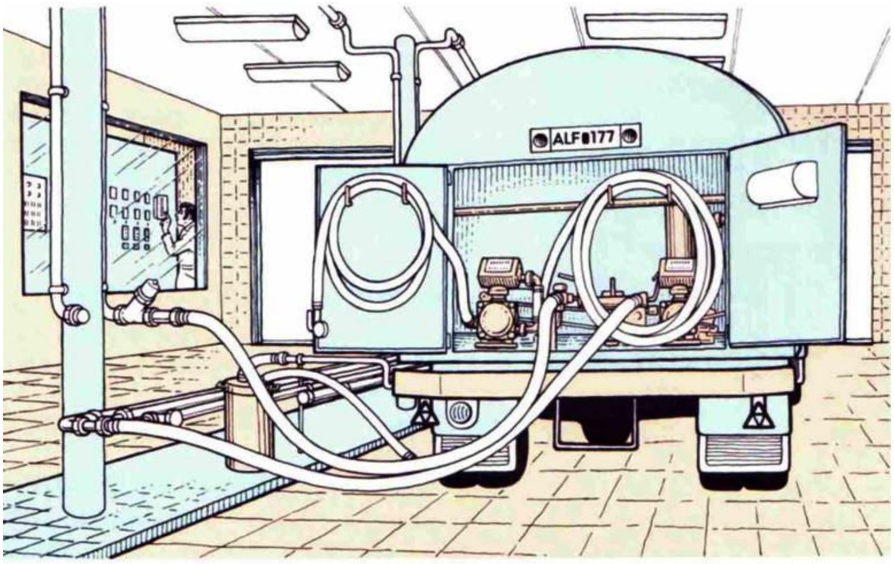
Churn reception

The milk in the churns is weighed in. The churns arrive from the lorry on a conveyor. On the way the lids are automatically removed. At the weighing station the milk is automatically emptied into a weighing bowl which indicates the quantity. The weighing machine operator enters the quantity against the identification of the producer. The weighing-in system is often designed so that the operator registers the producer identification on a key board before weighing in all the churns from that producer. The weights are then automatically totalled and recorded against the identification. The identification for the next supplier is then registered by the operator, and the process is repeated until all the milk has been weighed in. The weighing equipment must be well maintained and checked every day in order to ensure accuracy. From weighing-in, the raw milk is pumped to storage tanks to await processing.

The empty churns are conveyed to a cleaning station, where they are washed with water and detergent to remove all traces of milk. In some cases the clean churns continue to another station to be filled with feedstuff, which may be skim milk, buttermilk or whey. Finally the churns continue to a loading dock to await return to the farm. Large dairies can have several identical reception lines. This reception method is used for milks purchasing from small farmers but cow milk arrive in tanks usually in countries have advanced dairy.

Tanker reception

Tankers arriving at the dairy drive straight into a reception hall, often large enough to accommodate several vehicles, see Fig. 9. The milk is measured either by volume or by weight.



Measuring the received milk in a tanker reception hall

Figure 9. Covered tanker reception hall

Measuring by volume

This method uses a flow meter. It registers the air in the milk as well as the milk and the results are therefore not always reliable. It is important to prevent air from entering with the milk. Measuring can be improved by fitting a deaerator before the flow meter.

Fig.10. shows the equipment for measuring intake by volume. The tanker outlet valve is connected to a deaerator and from this the milk - free from air - is pumped through the flow meter, which continuously indicates the total flow. When all the milk has been delivered, a card is placed in the meter for recording the total volume.

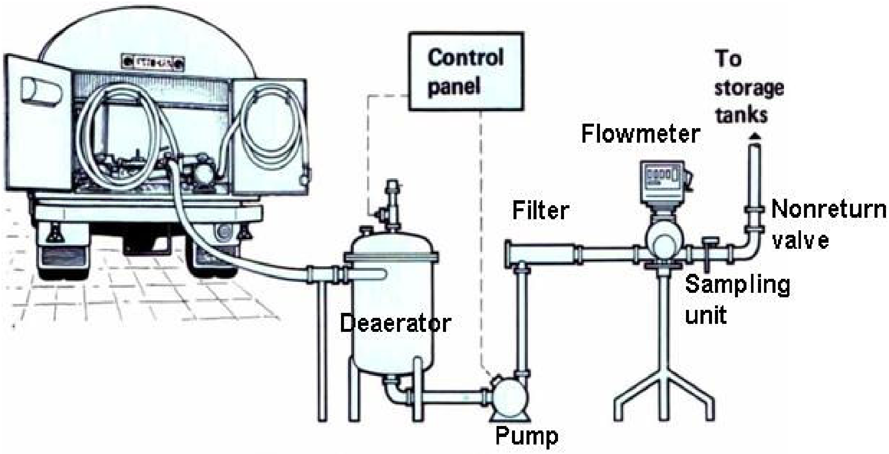


Figure 10. Tanker reception line (deareator, pump, filter, Volume meter, sampling tool, non-return valve)

The pump is started by the control equipment which senses when the milk in the deaerator has reached the preset level for preventing air from being sucked into the line. The pump is stopped as soon as the milk level drops below a certain level. After measuring, the milk is pumped to a storage (silo) tank.

Measuring by weight

The weighing-in of bulk-collected milk can take place in two ways:

- by weighing the tanker before and after unloading and then subtracting one value from the other.
- by means of special weighing tanks with load cells in the feet.

In the first alternative, the tanker is driven onto a weighbridge at the dairy. Operation may be manual or automatic. If manual, the operator records the weight against the driver's code number. Where the operation is automatic the necessary data are recorded when the driver places a card in a card scanner. Fig. 12 shows a tanker on a weighbridge. Before being weighed the tanker normally passes a car washing station. This is of special importance when the weather is bad.

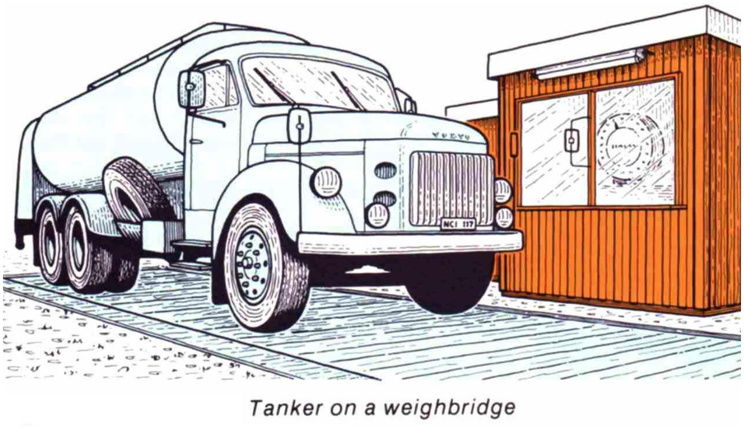


Figure 11. Measuring of milk by weight

When the gross weight of the tanker has been registered, the milk is delivered into the dairy. This may take place in line with a deaerator but not a flow meter. When empty, the tanker is weighed again and the tare weight is deducted from the previously registered gross weight. When the weighing-tank method is used, the milk is pumped from the tanker into a special tank, with load cells built into the feet, see Fig. 12.

The cells supply an electric signal that is always proportional to the weight of the tank. The strength of the signal increases with the weight of the tank as the milk enters the tank. The weight of the contents in the tank can be recorded when all the milk has been delivered. After this the milk is pumped to a silo tank.

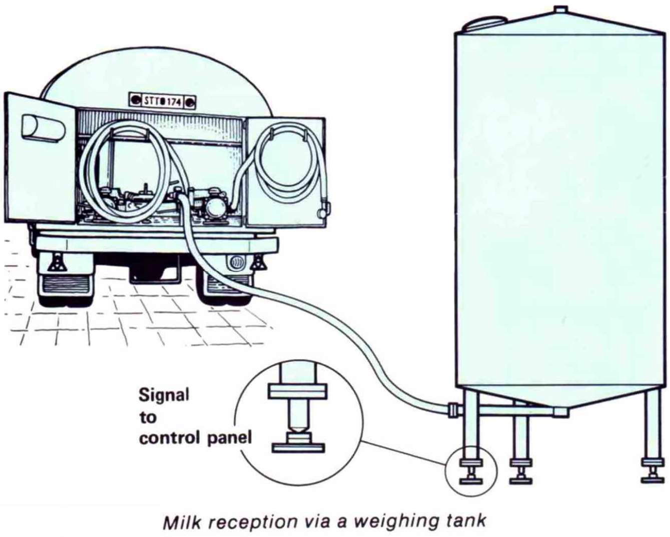


Figure 12. Milk reception via a weighing tank

Tanker cleaning

Tankers are cleaned every day, as a rule at the end of a collection round. If the tanker makes several rounds a day, cleaning should take place after each round. Cleaning can be carried out by connecting the tanker to a cleaning system while in the reception area or by driving it to a special cleaning station. Many dairies also clean the outside of their tankers every day so that they always look clean when they are on the road.

Chilling the received milk

Normally a temperature increase to slightly above + 4 °C is unavoidable during the transportation of the milk. Therefore the milk is usually cooled to below + 4 °C in a plate heat exchanger, before being stored in a silo tank to await processing.

Raw-milk storage

The untreated raw milk - whole milk - is stored in large vertical tanks - silo tanks - which have capacities from about 25 000 litres up to 150 000 litres. Normally, capacities range from 50 000 to 100 000 litres. Smaller silo tanks are often located indoors while the larger tanks are placed outdoors in order to reduce building costs. Outdoor silo tanks are of double-wall construction, with insulation between the walls. The inner tank is of stainless steel, polished on the inside, and the outer wall is usually of welded sheet metal.

Agitation in silo tanks

A silo tank is shown in Fig. 14. These large tanks must have some form of agitation arrangement to prevent cream separation by gravity. The agitation must be very smooth. Too violent agitation results in aeration of the milk and fat globule disintegration. This exposes the fat to attack from the lipase enzymes in the milk. Gentle agitation is therefore a basic rule in the treatment of milk. The tank in the illustration has a propeller agitator, often used with good results in silo tanks. In very high tanks it may be necessary to fit two agitators at different levels in order to obtain the required effect.

Outdoor silo tanks have a panel for ancillary equipment. The panels on the tanks all face inwards towards a covered central control station see Fig. 13.

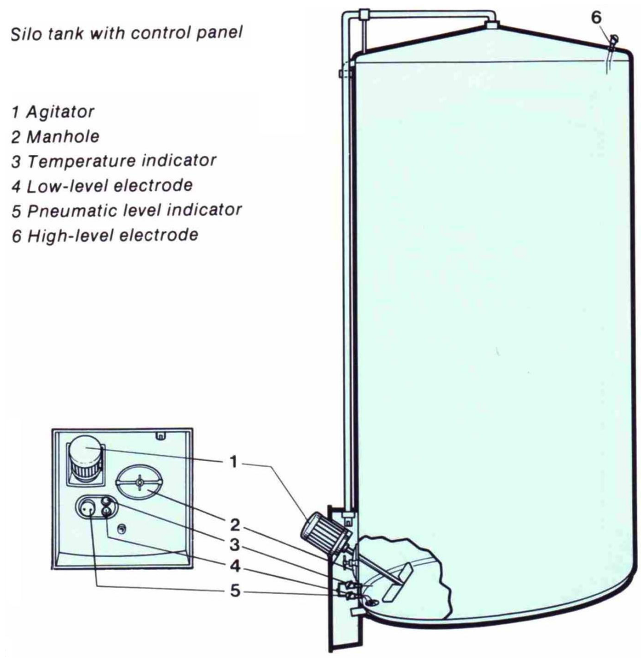


Figure 13. Silo tank with control panel

Tank temperature indication

The temperature in the tank is indicated on the tank control panel. Usually an ordinary thermometer is used, but it is becoming more common to use an electric transmitter, which transmits signals to a central monitoring station.

Level indication

There are various methods available for measuring the milk level in a tank. The pneumatic level indicator measures the static pressure represented by the head of liquid in the tank. The greater the pressure, the higher the milk level in the tank. The indicator transmits readings to an instrument.

Law-level protection
Ali agitation of milk must be gentle. The agitator must therefore not be started before it is covered with milk. An electrode is often fitted in the tank wall at the level required for starting the agitator. The agitator stops if the level in the tank drops below the electrode. This electrode is known as the law-level indicator (LL).

Overflow protection
A high-level electrode (HL) is fitted at the top of the tank in order to prevent overfilling. This electrode closes the inlet valve when the tank is full, and the milk supply is switched to the next tank.

Empty tank indication
During an emptying operation, it is important to know when the tank is completely empty. Otherwise any milk remaining when the outlet valve has closed will be rinsed out and lost during the subsequent cleaning procedure. The other risk is that air will be sucked into the line if emptying continues after the tank is dry. This will interfere with later treatment. Consequently an electrode (LLL) is often located in the drainage line to indicate when the last of the milk has left the tank. The signal from this electrode can be used to switch to another tank or to stop emptying.

5. General milk treatment

Farm milk in the silo tanks is the raw material for a wide range of dairy products: market milk, butter, yoghurt, cheese, milk powder, sterile products, condensed milk, etc. Ali these products make specific demands on the treatment of the raw material - demands which must be satisfied if high-quality standards are to be maintained. Regardless of what the end product will be, the milk used to make it must be treated in such a way that all pathogenic micro-organisms are killed. This is achieved by heat treatment. The process, known as pasteurization, has already been mentioned in the chapter "The building blocks of dairy processing". Pasteurization of milk is required by law in most countries, although in some countries cheese, for example, is made from selected unpasteurized milk. Similarly, laws in most countries demand that milk is clarified, i.e. treated for removal of solid matter. This consists of dirt particles, leucocytes (white blood corpuscles) and cells of udder tissue. The reason is that pasteurization is less likely to be effective if bacteria are ensconced in lumps and particles in the milk. Milk is clarified in filters or centrifuges; the latter method is considered more effective.

The other steps in milk treatment aim at modifying the composition of the milk and making it more suitable for subsequent manufacturing processes. The following operations come under the heading of general milk treatment:

- pasteurization to kill all pathogenic micro-organisms
- clarification to rid the milk of foreign particles and centrifugal separation to skim the cream from the skimmilk
- standardization of the fat content
- bactofuge treatment for physical separation of certain types micro-organisms from the milk
- homogenization to reduce the size of the fat globules so that they will remain dispersed instead of rising to form cream on the surface
- deaeration to expel gases and malodorous volatile substances

The different types of treatment are described in general terms in this chapter. More specific information can be found in the chapters on individual manufacturing processes.

Pasteurization

Pasteurization of milk is a very important process. Before it was introduced, milk was a dangerous source of infection as it is a perfect growth medium for micro-organisms. Diseases such as tuberculosis and typhus were spread by milk. Pasteurization kills the organisms that cause disease. If infections are sp read by pasteurized milk, the reason is either that heat treatment has not been properly performed or that the milk has been reinfected. It is therefore important to monitor the pasteurization process carefully in order to make sure that all the milk is treated in the prescribed manner.

Time/temperature combination

To ensure destruction of all pathogenic micro-organisms, it is necessary to heat the milk to a given temperature and hold it at that temperature for a certain length of time before it is cooled again. The combination of temperature and holding time is very important, as it determines the intensity of the heat treatment. Fig. 1 shows lethal-effect curves for coli bacteria and tubercle bacilli.

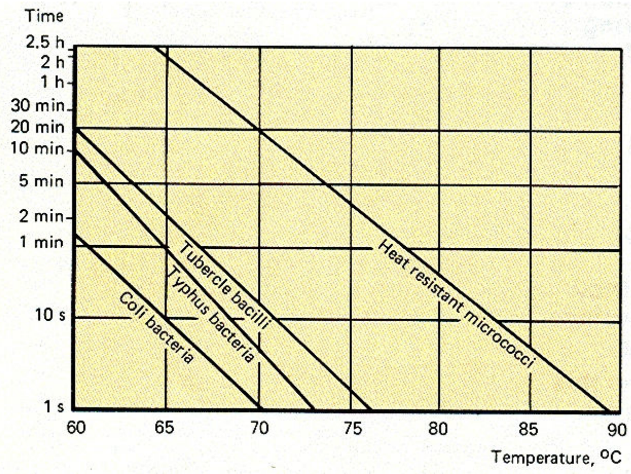


Figure 1. Lethal effect of bacteria

According to these curves coli bacteria are killed if the milk is heated to 70 °C and held at that temperature for about one second. At a temperature of 65 °C it takes a holding time of 10 seconds to kill coli bacteria. These two combinations, 70 °C/1 s and 65 °C/10 s, consequently have the same lethal effect.

Tubercle bacilli are more resistant to heat treatment than coli bacteria. A holding time of 20 seconds at 70 °C or about 2 minutes at 65 °C is required to ensure that they are all destroyed.

Purpose of the heat treatment

The primary purpose of heat treatment is to kill all micro-organisms capable of causing disease in human beings. Pasteurized milk must be entirely free from pathogens.
Apart from pathogenic micro-organisms, milk also contains other substances and micro-organisms which may spoil the taste and shelf life of milk products. A secondary purpose of pasteurization is therefore to destroy as many as possible of these other organisms and enzymatic systems in order to safeguard product quality. This requires more intensive heat treatment than is necessary to kill the pathogenic bacteria.
This secondary purpose of heat treatment has become more and more important as dairies have become larger. Longer intervals between deliveries mean that, despite modern cooling techniques, micro-organisms have more time to multiply and to develop enzymatic systems. The metabolism of micro-organisms also produces by-products which are sometimes toxic. In addition the constituents of the milk are degraded, the pH drops, etc. To overcome these problems, heat treatment must be applied as quickly as possible after the milk has arrived at the dairy.

Limiting factors for the heat treatment

Intensive heat treatment of milk is desirable from the microbiological point of view. But such treatment also involves a risk of adverse effects on the appearance, taste and nutritional value of the milk. Proteins in milk are denatured at high temperatures. This means that the cheese making properties of milk are drastically impaired by intensive heat treatment. Intensive heating produces changes in taste; first cooked flavour and then burnt flavour. The choice of time/ temperature combination is therefore a matter of optimization in which both microbiological effects and quality aspects must be taken into account.

Different degrees of heat treatment

The original type of pasteurization was a batch process. The milk was heated to 63 °C in open vats and held at that temperature for 30 minutes. Nowadays milk is almost always pasteurized in the continuous HTST process or sterilized in the UHT process.

HTST pasteurization

HTST is the abbreviation of High Temperature Short Time. The actual time/temperature combination varies according to the quality of the raw milk, the type of product treated, and the required keeping properties.

Milk

The HTST process for milk involves heating it to 72 - 75 °C with a 15 second holding time before it is cooled. Fig. 3 shows that the enzyme phosphatase, which is present in milk, is destroyed by this time/ temperature combination. The phosphatase test is therefore used to check that milk has been properly pasteurized. The test result must be negative; there must be no detectable phosphatase activity.

Cream and cultured products

Phosphatase tests cannot be used for products with fat contents above 8% as a certain reactivation of the enzyme takes place after pasteurization. The heat treatment must also be stronger, as fat is a poor heat conductor. Peroxidase, another enzyme, is therefore used for checking the pasteurization results for cream. The product is heated to a temperature of above 80 °C, with a hold ing time of about 5 seconds. This, more intensive, heat treatment, is sufficient to inactivate peroxidase. The test must be negative - there must be no detectable peroxidase activity in the product. The peroxidase test cannot be used for acidified products either. They are pasteurized intensively in order to coagulate whey proteins and to increase the water-binding properties (prevent formation of whey).

UHT treatment

UHT is the abbreviation of Ultra High Temperature. UHT treatment is a technique for preserving liquid food products by exposing them to brief, intense heating, normally to temperatures in the range of 135 140 °C. This kills micro-organisms which could otherwise destroy the products.

UHT treatment is a continuous process which takes place in a closed system that prevents the product from being contaminated by airborne micro-organisms. The product passes through heating and cooling stages in quick succession. Aseptic filling, preventing reinfection of the product, is an integral part of the process.

Two alternative methods of UHT treatment are used; indirect heating and cooling in heat exchangers and direct heating by means of steam injection and cooling by means of expansion under vacuum (see chapter "Sterilization").

Thermization

In many large dairies it is not possible to pasteurize and process all the milk immediately after delivery. Some of the milk must be stored in silo tanks for hours or days. Under these conditions even deep chilling is not enough to prevent serious quality deterioration.

Many dairies therefore pre-pasteurize milk. This process is called thermization. The milk is heated to 63 - 65 °C for about 15 seconds. Double pasteurization is forbidden by law in many countries, so thermization must stop short of pasteurization conditions - it must under no circumstances result in a negative phosphatase reaction. Thermization reduces the activity of micro-organisms. In order to prevent aerobic spore-forming bacteria from multiplying after heat treatment, the milk must be rapidly chilled to 4 °C or below. Many experts are of the opinion that thermization has a favourable effect on certain spore-forming bacteria. The heat treatment causes many spores to revert to the vegetative

state, which means that they are destroyed when the milk is subsequently pasteurized.
Thermization should only be applied in exceptional cases. The objective should be to pasteurize all the incoming milk within 24 hours of arrival at the dairy.

The heat exchanger

A heat exchanger is used to transfer heat by the indirect method. Several different types will be described later. It is possible to simplify heat transfer by representing the heat exchanger symbolically as two channels separated by a partition. Hot water flows through one channel and milk through the other.

The factors which affect the quantity of heat that can be transferred in a heat exchanger can be divided into three main categories:

- External process data
- Design of the heat exchanger
- Physical properties of the product and the heating or cooling medium

Different types of heat exchangers

Heat exchangers of different designs are found in the dairy industry. The most important are the plate heat exchanger, the scraped-surface heat exchanger and the shell-and-tube heat exchanger. The latter is used as a condenser in the energy plant, but special types, the so called double and triple tube heat exchangers, are used for special products in the dairy, for example in some UHT plants.

Shell-and-tube heat exchangers

The heat transfer area consists of a number of tubes through which the product flows. The heating medium flows through the space inside the shell and outside the tubes. Other types have U-shaped tubes in which the product flows through the length of the heat exchanger and back again, thereby increasing the amount of heat transfer.
Shell-and-tube heat exchangers are also used as condensers in refrigeration plants. In some high-pressure shell-and-tube heat exchangers the tubes are placed close together with common points of support. The tube bundle is enclosed in a horizontal vessel. Units of this type can operate at pressures of up to 10 MPa (100 bar).

Double and triple tube heat exchangers

The double and triple tube heat exchangers consist of concentric pipes, wound cylindrically to form coils. In the double tube the product flows in the inner pipe, surrounded by heating or cooling media in the outer channel between the two pipes. In the triple tube the product flows through the centre channel, surrounded by heating or cooling media in both the inner and outer channels.
Double and triple tubes can be used in all sections of the heat treatment plant, for example for heating with heating media, regenerative heating, holding, cooling with cooling media and regenerative cooling.
The heat transfer efficiency is approximately the same as for the plate heat exchanger. Contrary to the plate heat exchanger the double and triple tubes have no gaskets that require service or inspection at certain intervals. On the other hand they consist of a single, uninterrupted tubular channel that can not be opened, e.g. for checking the cleaning efficiency.

The scraped-surface heat exchanger

The scraped-surface heat exchanger is designed for heating and cooling of viscous, sticky and lumpy products and for crystallization of products. The operating pressures on the product side are high, often as much as 40 bar. Ali products that can be pumped can therefore be treated.
I a vertical type of scraped-surface heat exchanger the product flows through the inner tube and the heating or cooling media flow through a surrounding channel. A rotor with scraping blades, driven by a motor, continuously scrapes the heating/cooling surface in the product cylinder.
The heat exchanger has large inlet and outlet ports. This facilitates processing of products with solid particles with diameters up to 25 mm. Viscous products can also be treated, due to the high degree of

agitation by the rotating scrapers. The problem of excessive fouling of the surfaces is eliminated, as the heating surface is scraped during the process. Only a thin film remains on the inside of the cylinder. The clean, efficient surface maintained by the scraper blades during operation makes it possible to treat crystallizing products where solid particles would otherwise rapidly adhere to the heating surface. Typical products treated in the scraped-surface heat exchanger are jams, sweets, dressings, chocolate and peanut butter. It is also used for fats and oils for crystallization of margarine and shortenings, etc. The scraped-surface heat exchanger is also available in aseptic versions for aseptic processing.

Plate heat exchangers

Almost all heat treatment of dairy products is carried out in plate heat exchangers. The plate heat exchanger (often abbreviated PHE) consists of a pack of stainless steel plates, clamped in a frame. The frame may contain several separate packs - sections - in which different stages of treatment such as preheating, final heating, holding and cooling take place. The heating medium may be vacuum steam or hot water, and the cooling medium cold water, ice-water or brine, depending on the required product outlet temperature. Fig. 2 shows the principle of heating in a PHE.

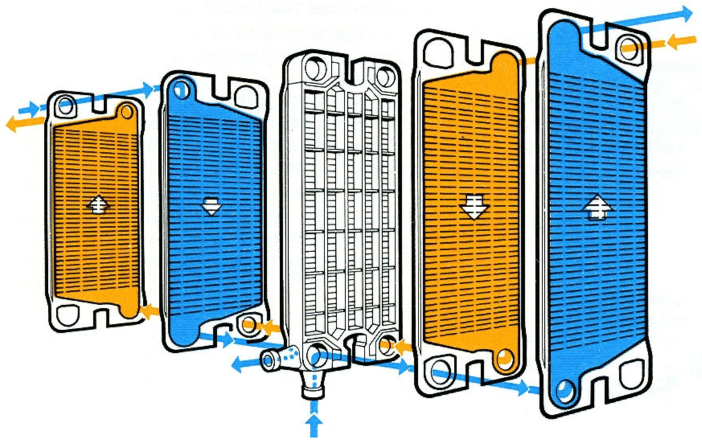


Figure 2. Plate heat exchanger with connecting plate between two sections

The plates in the pack are corrugated in a pattern designed for optimum heat transfer. The plate pack is compressed in the frame. Supporting points on the corrugations hold the plates apart so that thin rectangular channels are formed between them. (Fig. 2 is an exploded view with the plates separated to show the flow pattern more clearly.) The liquids enter and leave the channels through holes in the corners of the plates. Varying patterns of open and blind holes route the liquids from one channel to the next. Gaskets round the edges of the plates and round the holes form the boundaries of the channels and prevent leakage. The product is introduced through a corner hole into the first channel of the section and flows vertically through the channel. It leaves at the other end through a separately gasketed corner passage which conducts it past the next channel and from there into the next. The arrangement of the corner passages is such that the product flows through alternate channels in the plate pack. The heating or cooling medium is introduced at the other end of the section and passes, in the same way, through alternate plate channels. Each product channel consequently has channels for heating or cooling medium on both sides.

For efficient heat transfer the channels between the plates should be as narrow as possible; but both flow velocity and pressure drop will be high if a large volume of product must pass through these narrow channels. Neither of these effects is desirable and, to eliminate them, the passage of the product through the heat exchanger may be divided into a number of parallel flows. In this case the product flow is divided into two parallel flows which change direction four times in the section. The channels for the heating medium are divided into four parallel flows which change direction twice. This combination is written as 4 x 2/2 x 4, i.e. the number of parallel flows times the number of passes for the warm medium over the number of parallel flows, times the number of passes for the cold medium.

The pasteurizer

Milk comes from a silo tank to a balance tank and is pumped at a constant flow rate to the PHE. In the first section it is heated to pasteurization temperature. The heated milk then flows through a holding section, where no temperature treatment is applied, in order to obtain the necessary holding time. From the holding section the pasteurized milk continues to a cooling section where it is cooled to about + 4 °C.

Regenerative heat exchange

Milk is heated by absorbing heat from the heating medium through the partition plates of the heat exchanger. This means that the heating medium is cooled at the same time. Heat from the milk is transferred to the cooling medium in the cooling section.

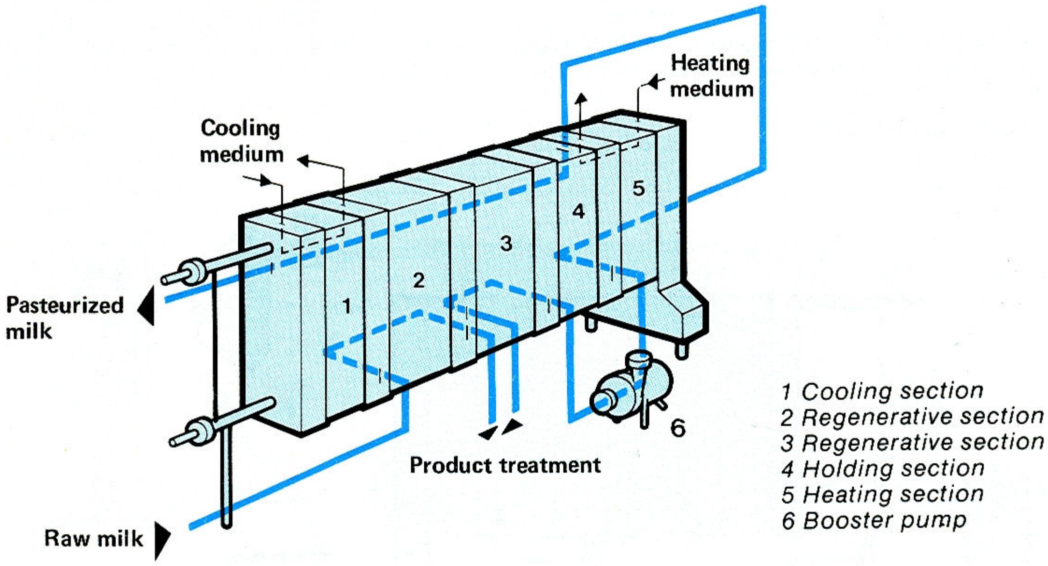


Figure 3. Plate pasteurizer with regenerative section and booster pump

The pasteurization process requires both heating of the incoming milk and cooling of the treated milk. These two stages in the process can therefore be combined. The milk, which is already pasteurized, is used as a heating medium for the incoming cold milk. This technique is called regenerative heat exchange and saves much energy.
Fig. 3. shows a plate pasteurizer with regenerative sections. Here the cold milk first enters the regenerative section and is preheated from 4 to about 72 °C by the pasteurized milk. At the same time the pasteurized milk is cooled to about 7 °C. The temperature of the regeneratively preheated milk therefore only needs to be increased by 3 °C (from 72 to 75 °C) by means of steam in the heating section. The cooling requirement for the pasteurized milk is only 3 °C (7 to 4 °C) compared to 71°C (75 to 4 °C).

Until recently a regenerative efficiency of 94% was maximum as the equipment then became very expensive (many plates). With today's energy prices regenerative efficiencies of 96%, and even a few tenths more, are profitable. The optimum heat recovery is defined as the heat recovery with the lowest annual costs - the lowest total of the annual operating and capital costs. Computer programs are used to calculate the optimum regenerative efficiency for a plant. The calculations are based on the temperature program for the pasteurizer, permitted pressure drops and the type of plate heat exchanger used. Other factors are the economic life, the interest and maintenance costs as well as costs for steam and cooling water. The computer program also shows how changes in important parameters will affect the result.

For a total temperature increase of 71°C (4 to 75 °C) a regenerative efficiency of 96% means that an increase of 96 : 100 x 71 = 68 degrees can be obtained by regeneration, so that the milk enters the heating section at 4 + 68 = 72 °C. The net thermal input in the heating section will therefore be sufficient to increase the temperature the last three degrees to 75 °C.

Preheating

Other operations, such as cream separation and homogenization, are often combined with pasteurization of milk. A certain optimum temperature is required. for example 63 °C for separation and about 70 °C for homogenization. The milk is therefore preheated to the required temperature in the pasteurizer, continues for treatment and then returns to the pasteurizer for further heating to the required final temperature.

Regenerative heating is therefore often carried out in two stages. The milk is preheated to the required temperature in the first regenerative section, and the treated product proceeds to the second regenerative section which completes the regenerative heating process.

Holding equipment

Correct heat treatment requires that the milk is held for a specified time at pasteurization temperature. This can be done either in an extra holding section, built into the plate heat exchanger, or in an external holding section. No heating or cooling takes place in the holding section, as the milk just flows through a passage, where the length and flow rate have been calculated so that the time in the holding section is equal to the required holding time. An external holding section usually consists of a length of pipe, arranged in a spiral or zig-zag pattern.

Accurate control of the flow rate is essential as the holding equipment is dimensioned for a specified holding time at a given flow rate. The holding time will change in inverse proportion to the flow rate in the holding section.

Prevention of reinfection

Care must be taken to avoid any risk of contamination of the pasteurized product by unpasteurized product or cooling medium. If any leakage should occur in the pasteurizer, it must be in the direction from pasteurized product to unpasteurized product or cooling medium. This means that the pressure of the pasteurized product must be higher than that on the other side of the heat exchanger plates. A booster pump is therefore installed in the product line, either after the holding section or before the heating section. The latter position minimizes the operating temperature of the pump and prolongs its life. The pump increases the pressure and maintains a positive differential on the pasteurized product side, throughout the regenerative and cooling sections of the pasteurizer. Installation of a booster pump is specified in the legal requirements for pasteurization in some countries. The system is shown in Fig. 4.

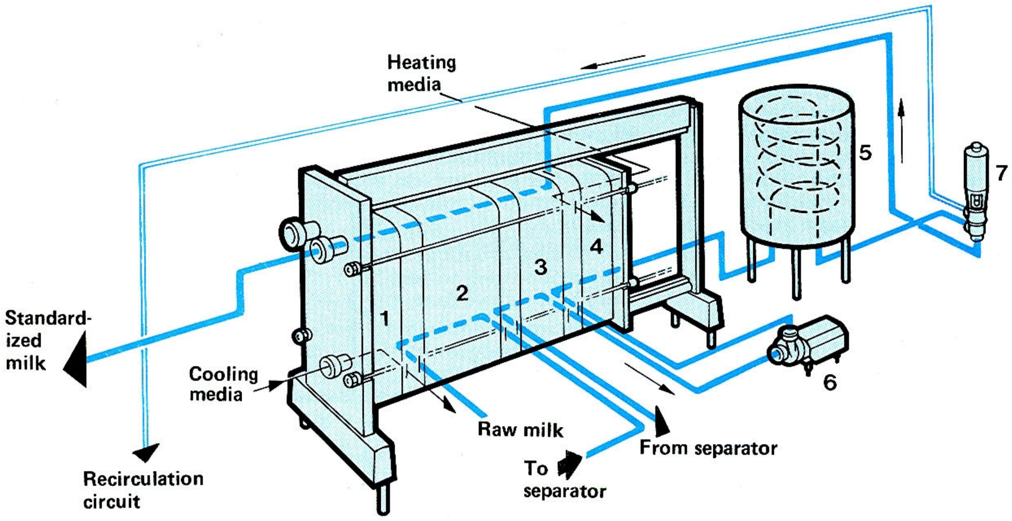


Figure 4. Pasteurizer with regenerative sections and booster pump in the product line, before the heating section (1:Cooling section; 2:Regenerative section; 3: Regenerative section; 4:Heating section; 5: External holding section; 6:Booster pump; 7:Flow diversion valve)

The complete pasteurizer

In a dairy a milk pasteurizer is completed with equipment for operation, supervision and control of the process.

Balance tank

The float-controlled inlet valve regulates the flow of milk and maintains a constant level in the balance tank. If the supply of milk is interrupted, the level will begin to drop. The pasteurizer must be full at all times during operation in order to prevent the product from burning on to the plates. The balance tank is therefore often fitted with a low-level electrode which transmits a signal as soon as the level reaches the minimum point. This signal actuates the flow diversion valve which recirculates the product to the balance tank. The milk is replaced by water and the pasteurizer shuts down when circulation has continued for a certain time.

Feed pump

The milk is pumped from the balance tank, which provides a constant head, through the pasteurizer by the feed pump.

Flow controller

The flow controller maintains the flow through the pasteurizer at the correct value. This guarantees stable temperature control and a constant length of the holding time for the required pasteurization effect.

Regenerative preheating

The untreated milk continues from the flow controller to the first section in the pasteurizer, the preheating section. Here it is regeneratively heated with pasteurized milk, which is cooled at the same time. If the milk is to be treated at a temperature between the inlet and outlet temperatures of the regenerative section, for example separation at 65 °C, the regenerative section is divided into two sections. The first section is dimensioned so that the milk leaves at the required temperature of 65 °C. After separation the milk returns to the pasteurizer which completes the regenerative preheating in the second section.

Pasteurization
Final heating to pasteurization temperature with hot water or vacuum steam takes place in the heating section of the pasteurizer. The hot milk continues to the holding section (or to an external holding section). After the holding time, the temperature of the milk is checked by a sensor in the line. It transmits a continuous signal to the temperature controller in the control panel. The same signal is also transmitted to a recording instrument which records the pasteurization temperature.

Flow diversion
A sensor after the holding section transmits a signal to the temperature monitor. As soon as this signal drops below a preset value, corresponding to a specified minimum temperature, the monitor switches the flow diversion valve to diversion flow. In many plants the position of the flow diversion valve is recorded together with the pasteurization temperature.

Cooling
After the holding section the milk is returned to the regenerative section(s) for cooling. Here the pasteurized milk transfers the heat to the cold, incoming milk. The outgoing pasteurized milk is then chilled, first with cold water and then with ice-water, a glycol solution or some other refrigerant, depending on the required temperature. The temperature of the chilled milk is normally recorded together with the pasteurization temperature and the position of the flow diversion valve. The graph consequently shows three curves.

Clarification and cream separation

Centrifugal separation is a very common process in dairies. Typical tasks include:

- clarification - removal of solid impurities from milk prior to
- pasteurization
- skimming - separation of cream from skim milk
- whey separation - separation of fat from whey
- bactofuge treatment - separation of bacteria from milk
- quarg separation - separation of quarg curd from whey
- butter-oil purification - separation of serum phase from anhydrous milk fat

Clarification and skimming are described in this chapter. Other types of separation are described in later chapters. We will start with a brief review of separation theory.

Separation by gravity
Historically speaking the centrifugal separator is a recent invention. Up to a hundred years ago the techniql1.e used for separating one substance from another was the natural process of sedimentation by gravity. Sedimentation takes place all the time. Clay particles moving in puddles will soon settle, leaving the water clear. Clouds of sand stirred up by waves or by the feet of bathers do the same. Oil that escapes into the sea is lighter than water, rises and forms oil slicks on the surface.
Sedimentation by gravity was also the original technique used in dairying to separate fat from milk. Milk, fresh from the cow, is left in a vessel. After some time, the fat globules aggregate and float to the surface where they form a layer of cream on top of the milk. This can then be skimmed by hand.

Requirements for sedimentation
The liquid to be treated must be a dispersion - a mixture of two or more phases, one of which is continuous. In milk it is the milk serum, or skim milk, that is the continuous phase. Fat is dispersed in the skim milk in the form of globules with diameters from 0.5 to 10 μm. Milk also contains a third phase, consisting of dispersed solid particles such as udder cells, dirt from the cowshed, etc.
The phases to be separated must not be soluble in each other. Substances in solution can not be separated by means of sedimentation.
Dissolved lactose cannot be separated by means of centrifugation. It can, however, be made to

crystallize by subjecting the milk to certain processes. The lactose crystals can then be separated by sedimentation.

The phases to be separated must also have different densities. The phases in milk satisfy this requirement; the solid impurities have a higher density than skim milk, and the fat particles have a lower density.

Separation by centrifugal force

Sedimentation velocity

A field of centrifugal force is generated if a vessel is filled with liquid and spun. This creates a centrifugal acceleration a. The centrifugal acceleration is not constant. It increases with distance from the axis of rotation (radius *r)* and with the speed of rotation, expressed as angular velocity *w.* The acceleration can be calculated by the formula

$$a = r\,\omega^2 \quad \text{(eq.1.)}$$

Each particle in the rotating vessel is subjected to a force. The magnitude is determined by the distance of the particle from the axis of rotation and the angular velocity. The force increases if the particle is further away from the centre and also if the speed of rotation is increased.

The following formula is obtained if the centrifugal acceleration, a, expressed as $r\,\omega^2$, is substituted for the acceleration, *g,* due to the gravitational attraction of the earth in equation 1.

$$V = \frac{d^2(\rho_{pl} - \rho_{fat})}{18\eta} g \quad \text{(eq.2)}$$

V: velocity of settling; d: diameter of fat globule; ρ_{pl}: plasma density; ρ_{fat}: density of milk fat;

η: viscosity of whole milk; g: centrifugal acceleration

Equation 2 can be used to calculate the sedimentation velocity, *v,* of each particle in the centrifuge.

Continuous separation of milk

In a centrifugal milk clarifier, the milk is introduced into the separation channels at the outer edge of the disc stack, flows radially inwards through the channels towards the axis of rotation and leaves through an axial outlet. On the way through the channels the solid impurities are separated and thrown back along the lower sides of the disks to the periphery of the separator bowl. There they are collected in the sediment space. As the milk passes along the full radial width of the discs, the time of passage also allows very small particles to become separated, i.e. the diameter of the limit particle in the clarifier is the smallest possible.

Fat globules are separated from the milk in the disc stack of a cream-skimming centrifugal separator as follows. The milk is introduced through vertically aligned distribution holes in the discs at a certain distance from the edge of the disc stack. Under the influence of the centrifugal force the particles and droplets in the milk begin to settle radially outwards or inwards in the separation channels, according to their density relative to that of the continuous medium (skim milk).

As in the clarifier the high-density solid impurities in the milk will quickly settle outwards towards the periphery of the separator and collect in the sediment space. Sedimentation of solids is assisted by the fact that the milk in the channels in this case moves outwards towards the periphery of the disc

stack.
The cream, i.e. the fat globules, has a lower density than the skim milk and therefore moves inwards in the channels, towards the axis of rotation. The cream continues to an axial outlet.
The skim milk moves outwards to the space outside the disc stack and from there through a channel between the top of the disc stack and the conical hood of the separator bowl to a concentric skim milk outlet.

Skimming efficiency
The amount of fat that can be separated from milk depends on the design of the separator and the rate at which the milk flows through it. The separator is designed for a given flow rate, separating fat globules from the skim milk at a stated efficiency. The smallest fat globules do not have time to settle at the specified flow rate but are carried out of the separator with the skim milk. The remaining fat content in the skim milk is normally between 0.04 and 0.07% and the skimming ability of the machine is then said to be 0.04 - 0.07.
The flow velocity through the separation channels will be reduced if the flow rate through the machine is reduced. This gives the fat globules more time to settle and be discharged through the cream outlet. The skimming efficiency of a separator consequently increases with reduced throughput and vice versa.

Fat content of cream
The whole milk supplied to the separator is discharged as two flows: skim milk and cream, of which the cream normally represents about 10% of the total throughput. The proportion discharged as cream determines the fat content of the cream. If the who le milk contains 4% fat and the throughput is 20 000 l/h, the total amount of fat passing through the separator will be 4 x 20 000 : 100 = 800 l/h. Assume that cream with a fat content of 40% is required. This amount of fat must be diluted with a certain amount of skim milk. The total amount of liquid discharged as 40% cream will then be 800 x 100: 40 = 2 000 l/h. 800 l/h is pure fat, and the remaining 1 200 l/h is skim milk.
Installation of throttling valves in the cream and skim milk outlets makes it possible to adjust the relative volumes of the two flows in order to obtain the required fat content in the cream. The increasing viscosity limits the fat content of the cream, see under "Regulation of fat content in cream" in this chapter.

Construction of the separator

Modern separators are of two types, semi-open and hermetic.
In the semi-open separator the milk is supplied to the separator bowl at atmospheric pressure through a stationary axial inlet tube. When the milk enters the bell-shaped, ribbed distributor, it is accelerated to the speed of rotation of the bowl before it continues into the separation channels in the disc stack.

The centrifugal force throws the milk outwards to form a ring with a cylindrical inner surface. This is in contact with air at atmospheric pressure, which means that the pressure of the milk at the surface is also atmospheric. It increases progressively with increasing distance from the axis of rotation to a maximum at the periphery of the bowl. In the semi-open separator the cream and milk outlets have special outlet devices paring discs. In these the kinetic energy of the rapidly rotating milk and cream is converted into pressure, so that the paring discs pump the separated skim milk and cream out of the machine. Because of this design the semi-open separators are usually called paring-disc separators.
In the hermetic separator, the milk is supplied to the bowl from below through a channel in the bowl spindle. The milk is pumped by a centrifugal pump. When it enters the bowl it is accelerated to the same speed of rotation as the bowl and then continues through the distribution holes to the disc stack.

The bowl of a hermetic separator is completely filled with milk during operation. There is no air in the centre. The hermetic separator can therefore be regarded as part of a closed pipe system. The pressure, generated by the centrifugal pump, is sufficient to overcome the flow resistance through the separator and to provide a moderate discharge pressure for the cream and skim milk. Higher pressures are normally required for transport of the products in the pipes after the separator. Impellers are therefore built into the outlet housings. The diameter of these impellers can be sized to suit the outlet pressure requirements.

Main parts of the separators

Fig. 5. shows a hermetic separator with horizontal and vertical drives for the separator bowl. The horizontal drive consists of an electric motor, a coupling with rubber buffers, and a drive shaft with a worm wheel. The vertical drive consists of a shaft - the bowl spindle - on top of which the separator bowl is mounted. Power from the motor is transmitted from the worm wheel on the horizontal drive shaft to a worm gear of the spindle. Precision roller bearings support the drive components, eliminating vibration. The bearings are splash lubricated by the worm wheel, which runs partially immersed in an oil bath in the base of the frame. A pneumatic brake, acting on the coupling pulley, a revolution counter button for speed indication, an oil filler plug and an oil gauge glass are also mounted on the frame.

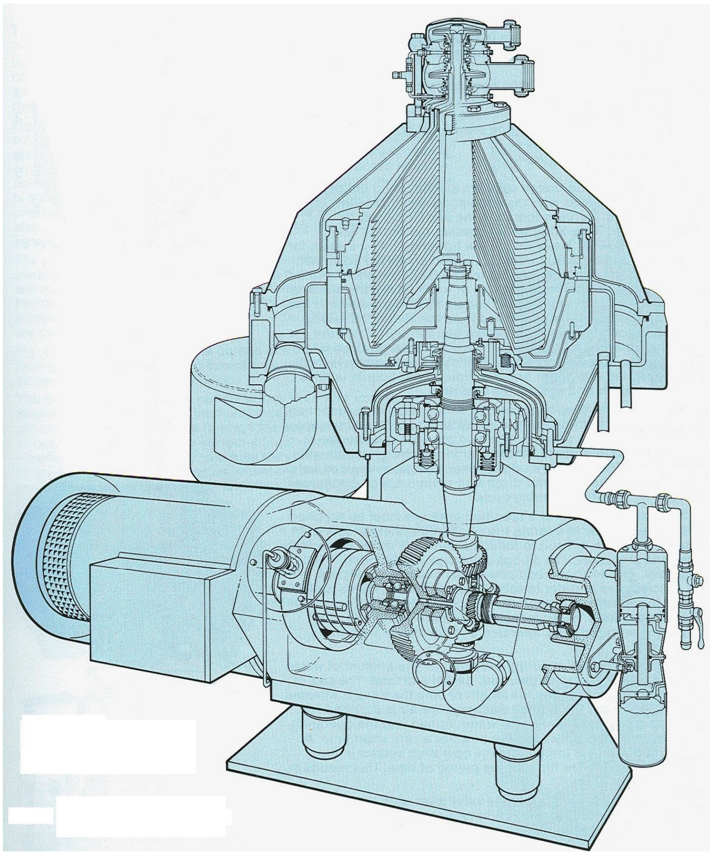
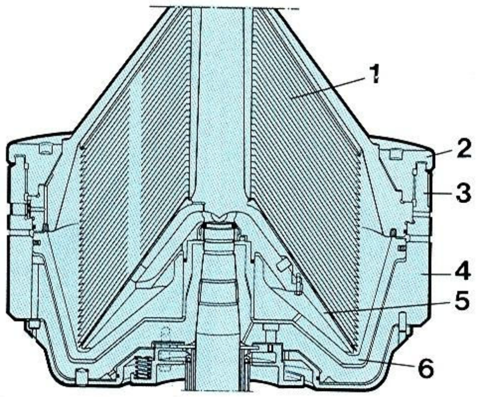


Figure 5. Sectional view of modern hermetic separator

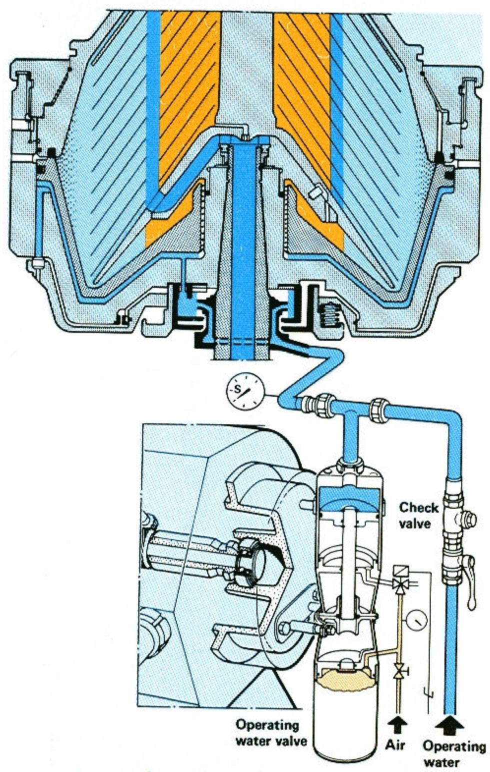
The separator is started, stopped and monitored from a control cabinet close to the machine. There is also equipment for automatic timing of solids ejection during operation and for total ejection of the bowl contents during cleaning. Fig. 6. shows a section through the bowl of a self-cleaning hermetic separator. The bowl consists of two main sections, the body and the hood. They are held together by a threaded lock ring. The disc stack is clamped between the hood and the distributor at the centre of the bowl.

The discharge system
A number of sediment discharge slots are placed round the periphery of the bowl body and level with the angular sediment receiver, built into the frame hood. During separation the bowl is closed by hydraulic pressure. "Operating water" presses the sliding bowl bottom upwards against a seal ring in the bowl hood. The system for operation of the sliding bowl bottom is located under the bowl. With this system the space between the sliding bowl bottom and the floor of the bowl can be filled with or emptied of water. When the space is full, the water forces the sliding bowl bottom upwards and keeps the bowl closed. When the water is drained from the space, the sliding bowl bottom descends, opening a narrow gap through which the sediment is discharged from the bowl, via the discharge slots, into the sediment receiver. The space under the sliding bowl bottom is then immediately refilled with water and the sliding bowl bottom is once more forced upwards and against the seal ring.



1 Disc stack
2 Lock ring
3 Bowl hood
4 Bowl
5 Distributor
6 Sliding bowl bottom

Figure 6. *Section through the bowl of a self-cleaning hermetic separator*



During separation the bowl is opened for a very short time (less than one second), which is sufficient to eject all sludge in the sludge space but too short to lose any product. It is also possible to delay the closing of the bowl in order to obtain a larger discharge, which will eject the entire content of the sludge space. A larger amount of water is then supplied to the separator discharge system. Large discharges are used during the bowl cleaning cycle.

A specified volume of water at a specified pressure must be supplied to the machine in order to operate the discharge system properly. In many plants it may be difficult to fulfil the demands made on correct flow rates and pressures. The sludge discharge is then often unsatisfactory. Fig 7. shows equipment that has been designed round a special valve in order to solve these problems. Mains water is supplied to the valve via the separator's auxiliary box. This box contains the necessary valves, constant-pressure valves, etc. The special valve is pneumatically operated and controlled from the control cabinet.

Figure 7. Tipical discharge performance

The valve is filled with water during production. The amount of water is sufficient for several discharges, both partial and total. The size of the discharge is determined by the length of time the valve is affected by the compressed air. For a small discharge the air is supplied for such a short time that the amount of water, forced into the operating system of the bowl, will only open the bowl for a very short time. A larger amount of water is forced into the operating system if the compressed air is supplied for a longer period of time. This results in a greater discharge.

New operating water is supplied to the valve after each discharge with exactly the same pressure and flow rate each time. This guarantees the discharge function, regardless of fluctuations in the mains water.

Separation of milk
During separation in a paring-disc separator, preheated milk comes from the regenerative section of the pasteurizer and is introduced into the separator bowl from above through the stationary, axial inlet tube. The heavier solid particles settle outwards and are deposited in the sediment space. Cream moves inwards towards the axis of rotation and passes through channels to the cream paring chamber. The skim milk leaves the disc stack at the outer edge and passes between the top disc and the bowl hood to the skim milk paring chamber.

The separator outlets
The fat content of the discharged cream is regulated by means of throttling valves in the separator outlets. If whole milk with a fat content of 4% is separated and cream with a fat content of 40% is to be obtained, the cream flow in the outlet will be 2 000 l/h at a throughput of 20 000 l/h.
The rims of the stationary paring discs dip into the rotating columns of liquid, continuously scooping out a certain amount. The kinetic energy of the rotating liquid is converted into pressure in the paring disc, and the pressure is always equal to the pressure drop in the down stream line. If this pressure drop is increased, the pressure of the liquid in the bowl will also increase, as this pressure is generated by the mechanical acceleration equipment at the inlet. The pressure increase means that the liquid level in the bowl moves inwards and will cover more of the paring disc. More kinetic energy will then be converted into pressure. In this way the effects of the throttling at the outlets are automatically counteracted. In order to prevent aeration of the product it is important that the paring discs are covered with liquid.
Fig. 8. shows the bowl and the outlets of a hermetic separator. During separation the bowl is completely filled with product and no air can be mixed into the product.

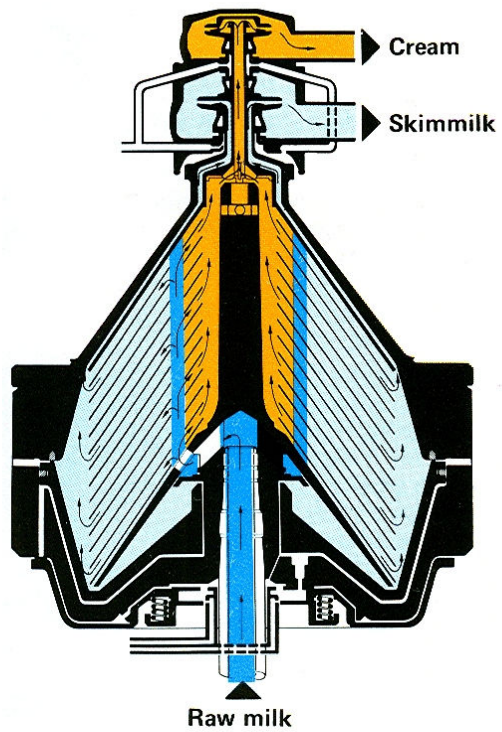


Figure 8. Inlet and outlet for cream and skim milk in a hermetic separator

The product pressure in the outlet, before the outlet impellers, is determined by the selected inlet pressure and the pressure drop obtained during the passage through the separator. By combining the chosen inlet pressure with a correct adjustment of the impeller diameter, it is therefore easy to create the correct outlet product pressures. This means that no unnecessary throttling is needed in the product line after the separator, which saves energy.

Control of the fat content in cream

The volume of cream discharged from the separator is controlled by means of a throttling valve in the cream outlet. If the valve is completely closed, all the milk will be discharged through the skim milk outlet. Progressively larger amounts of cream, with a progressively diminishing fat content, will be discharged from the cream outlet if the valve is gradually opened.

Standardization of the fat content of milk

The fat content of the incoming whole milk varies. Standardization means that the milk is processed to market milk with a specified, constant fat content. If the standardized fat content is higher than that of the incoming whole milk, the process will involve removing some of the skim milk, and the dairy will have a skim milk surplus. However, standardization normally reduces the fat content and the process therefore leaves a surplus of fat which can be used, for example, for butter making.

The process of standardization can be carried out in two different ways: batch standardization and direct in-line standardization. The first stage in both methods is to separate whole milk into cream and skim milk. (Fig. 9.)

Two methods, pre-standardization and post-standardization, are used in batch processing. Pre-standardization means that the milk is standardized before pasteurization. When standardizing to a fat content higher than the raw-milk fat content, cream is mixed with the milk in tanks in the proportions which give the required fat content. In order to standardize to a lower fat content, the raw whole milk is diluted with separated skim milk. The standardized milk is pasteurized after analysis and adjustment.

Post-standardization means that pasteurized whole milk is mixed in tanks with cream or skim milk, according to whether the fat content is to be adjusted upwards or downwards, in the same way as for pre-standardization. Some risk of reinfection is involved as post-standardization involves mixing already pasteurized products. Both methods require large tanks and the analysis and adjustment are labour-intensive.

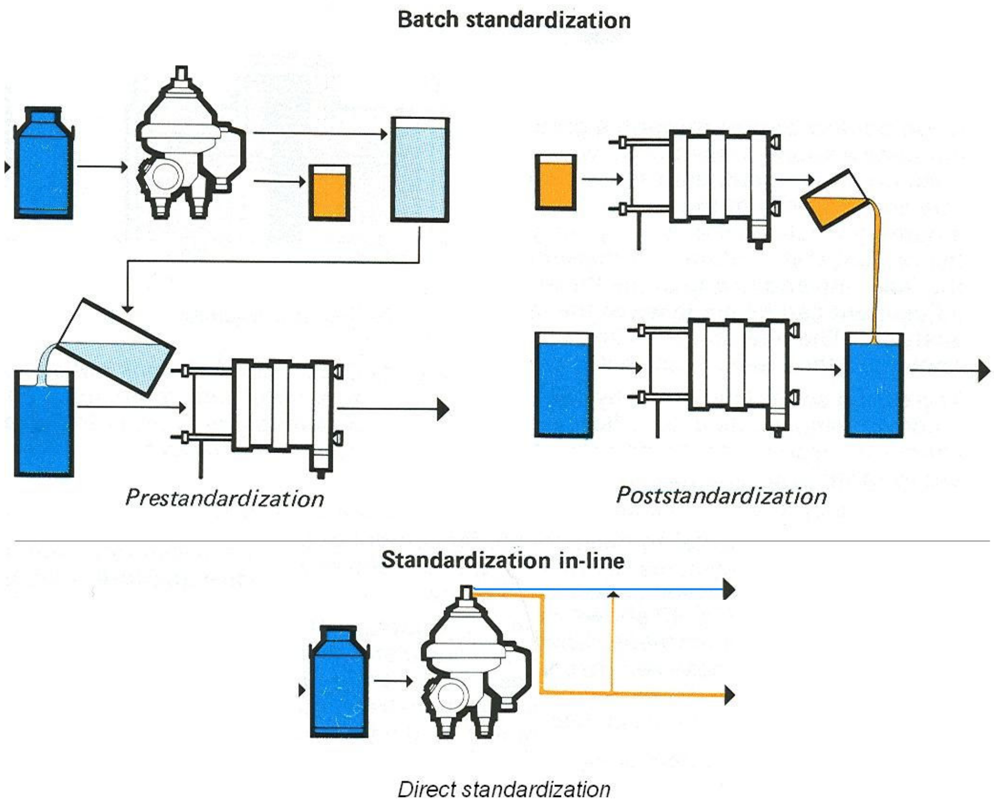


Figure 9. Methods of fat standardization

The second method, direct standardization, has therefore been an attractive alternative for many years. In this method, the fat content is adjusted to the required level by remixing of a calculated proportion of the cream from the separator to the skim milk line. The difficulty of obtaining separated cream with a precisely controlled fat content has often made it necessary to analyse the standardized milk afterwards and carry out a final adjustment in tanks.
New types of transmitters for measurement of the fat content have been developed in recent years. Several systems have been designed for automatic standardization of milk. One system, which has worked well in practice in many dairies, will be described in this chapter.

Automatic direct standardization

Direct standardization starts with separation of preheated whole milk into skim milk and cream with a constant fat content. A regulated amount of cream is then remixed with the skim milk in an in-line system immediately after the separator in order to obtain standardized milk of a required fat content.
For precision in the process it is necessary to measure variable parameters such as:

- fluctuations in the fat content of the incoming milk
- fluctuations in throughput
- fluctuations in preheating temperature

Most of the variables are interdependent; any deviation in one stage of the process often results in deviations in all stages. The precision of the standardization will suffer and the fat content of the standardized cream and milk will deviate from the specified value if such deviations can not be corrected rapidly.
The outlet pressure in the skim milk outlet must be maintained constant in order to make it possible to carry out accurate standardization. This pressure must be kept, regardless of variations in flow or pressure drop caused by the equipment after the separator. The previously described constant-pressure valves maintain this pressure.

The fat standardization process is controlled by two control circuits.

- The first control circuit regulates the flow from the cream outlet of the separator. The fat content of the cream is kept at a constant, preset value regardless of any changes in throughput or fat content of the milk supplied to the separator.
- The second circuit controls the amount of cream that is remixed with the skim milk for standardized milk of the specified fat content. Surplus standardized cream is removed. This circuit operates with ratio control, which means that the cream and skim milk ratio in the mixture is controlled continuously.

The complete direct standardization process

Fig. 10. shows the complete process for automatic, direct standardization of milk. The pressure control system at the skim milk outlet maintains a constant pressure, regardless of fluctuations in the pressure drop over down stream equipment. The cream regulating system maintains a constant fat content in the cream, discharged from the separator, by adjusting the flow of cream discharged. This adjustment is independent of variations in the throughput or in the fat content of the incoming whole milk. Finally, the ratio controller mixes cream of constant fat content with skim milk in the necessary proportions to give standardized milk of a specified fat content.

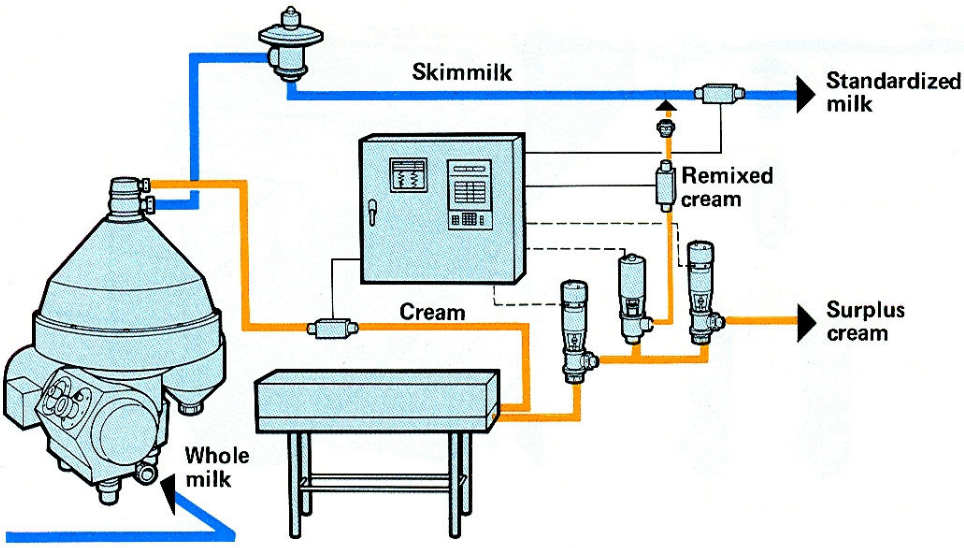


Figure 10. Complete plant for direct standardization

Bactofuge treatment

Bactofuge treatment is a method of removing undesirable microorganisms mechanically in a specially designed, high-speed separator - a Bactofuge. The method was developed to complement heat treatment in improving the keeping quality of milk with a high initial bacteria count. Fortunately, some of the micro-organisms which are most resistant to heat treatment are also the heaviest and therefore the easiest to remove by means of centrifugation. This process is important in cheese manufacture, as the heat resistant but heavy spores can cause late fermentation.

The Bactofuge in Fig. 11. is of hermetic design. During separation of the cheese milk the bacteria concentrate (bactofugate), which amounts to 2 - 3% of the total milk throughput, is discharged continuously through the heavy-phase outlet of the Bactofuge. Because of the high centrifugal force to which the milk has been exposed the bactofugate has high protein content.

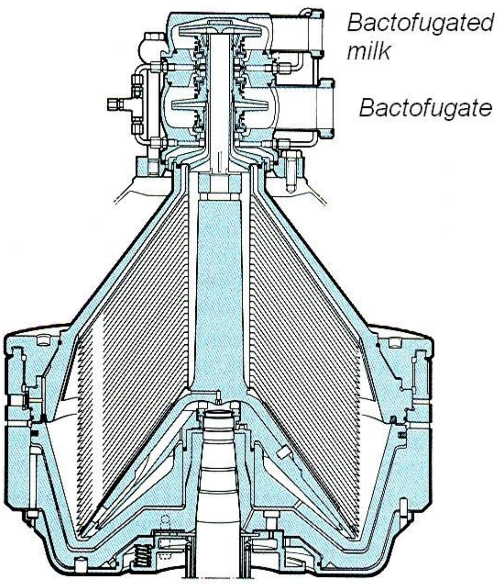


Figure 11. Bowl section of the Bactofuge

Bactofugate sterilization

After separation, the bactofugate can continue directly to a special bactofugate sterilizer. The separated micro-organisms are instantly killed by live steam at 130 - 140 oC when the bactofugate is injected inte a steam chamber (infusion). The sterilization temperature is maintained for 3 - 4 seconds and then the bactofugate is cooled. Flavour and nutritional value remain virtually unaffected because of the very short holding time. After sterilization the bactofugate can be remixed with the rest of the milk.

Homogenization

The tendency of milk fat to float in milk and form a creamline on the surface makes it possible to separate fat from milk. In the manufacture of certain dairy products, however, this property is undesirable. Examples are chocolate milk, coffee cream, sterile milk and, to some extent, ordinary market milk. Sedimentation of fat can be effectively prevented by homogenization of the product.

Homogenization means that the fat globules are subjected to mechanical treatment which breaks them down into smaller globules, uniformly dispersed in the milk. This treatment reduces the mean diameter of the fat globules by a factor of about 10. The sedimentation velocity of these small fat particles is extremely low, and the homogenized product is therefore virtually stable.
The number of fat globules in homogenized milk is about 10 000 times greater than in untreated milk. The total interface area between fat globules and milk serum is increased by a factor of 10. There is not enough original membrane material to form membranes round all the new fat globules. It is believed that new membranes are formed from certain proteins which resemble membrane proteins.
The formation of new membranes takes some time, during which many of the globules are unprotected. If such globules collide they coalesce into lumps. The distance between fat globules is short if the fat content of homogenized milk is high, and the globules will colloid and form lumps before membranes can be formed and prevent further coalescence. At lower fat concentrations the distance between globules is greater, and they have time to adsorb membrane material before colliding. No coalescence occurs.

The homogenization temperature also affects the degree of coalescence. The higher the temperature, the fewer lumps are formed.
Homogenization may be either total or partial. Ali the milk is processed in total homogenization. The fat content is low and there is no coalescence of fat. The resulting product, micronized milk, shows little or no tendency to creamlining. In partial homogenization only the cream fraction is treated. The fat content is high and the globules coalesce. A defective product with a very thick creamline will be obtained if homogenized cream with a high degree of coalescence is used in the manufacture of market milk. Such milk has become viscolized.

The effect of homogenization on the chemical and physical structure of milk has many advantages:

- Uniform distribution of fat, no creamline
- Whiter, more appetizing colour
- Faster coagulation in the manufacture of rennet cheese
- Reduced sensitivity to oxidation
- More full-bodied flavour

There are also certain disadvantages with homogenization:

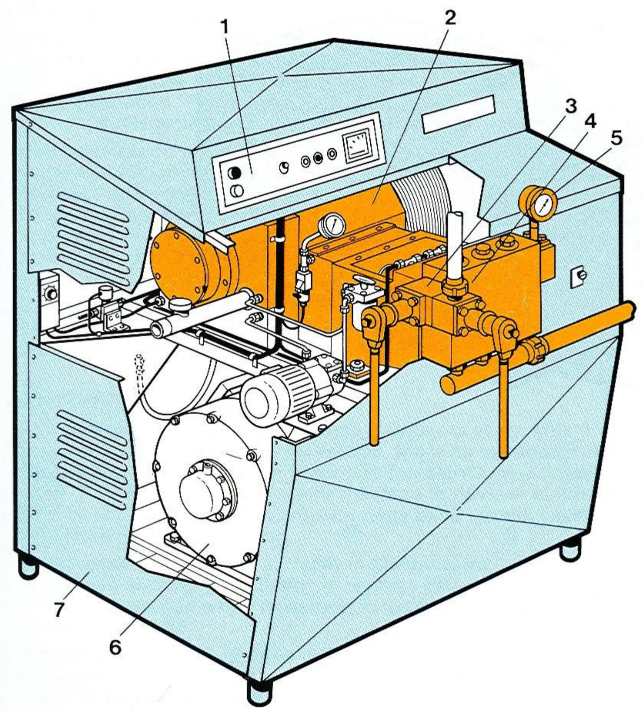
- The milk can not be efficiently separated
- Sensitivity to sunlight - the flavour rapidly becomes metallic
- Sensitivity to lipase attack
- Low thermal stability of the protein
- *Rate of Syneresis decrease and become slower (disadvantage in cheese making)*

The latter item means that homogenization must be carried out as the last stage in the manufacture of sterile milk, as there will otherwise be a risk of proteins coagulating at the high temperatures involved in sterilization. This would result in protein sediment in the milk packages.

The homogenizer

A cutaway view of a homogenizer is shown in Fig. 12. The main components are a high-pressure pump (usually a three-cylinder piston pump) and a back-pressure device, the homogenizer head. The pump is driven by a powerful electric motor via a crankshaft and connecting-rod transmission which converts the rotary motion of the motor to the reciprocating motion of the pump pistons.

Figure 12. Cutaway view of a homogenizer



1 Control panel
2 Transmission
3 Homogenizer head
4 Cylinder block
5 High-pressure gauge
6 Motor
7 Frame

The pistons run in cylinders in a high-pressure block. They are made of highly resistant materials. Piston rings prevent oil from leaking into the product. The machine is fitted with double piston rings. Water can be supplied to the space between them to cool the pistons. Steam or condensate can also be supplied in order to prevent reinfection in aseptic processes.

The homogenizer head

The pump increases the pressure of the milk from about 80 220 kPa (0.8 - 2.2 bar) at the inlet to a homogenizing pressure of between 10 and 20 MPa (100 - 200 bar) depending on the product. The homogenization pressure is adjusted with a lever, and the pressure can be read on a high-pressure gauge.

The homogenizer head is built with many components. A cylindrical outer ring surrounds a specially shaped care with four vanes. These parts are precision ground and fit together with a very narrow gap for the milk. The homogenizer ring is attached to the outer ring in such a way that the inner surface is perpendicular to the outlet of the gap. The milk is supplied at high pressure into the space between the outer ring and the care. In the narrow gap the high pressure is converted into kinetic energy. The velocity of the milk becomes very high (200 - 300 m/s) in the narrow, ring-shaped gap. When the milk leaves the gap it impacts at high velocity on the inside of the homogenizer ring and is forced to change direction, see Fig. 63. The resulting homogenization effect is produced by three collaborating factors:

- Passage through the narrow gap in the homogenizer head at high velocity subjects the fat globules to very powerful shearing forces, which deform, elongate and shatter the spherical globules.
- The acceleration of the liquid in the gap is accompanied by a pressure drop, possibly to below the vapour pressure of fat. This creates cavitation in which the globules are subjected to very powerful implosive forces.
- Further shattering takes place when the fat globules impact at high velocity in the homogenizer ring.

Two-stage homogenization

Homogenization efficiency can be increased by two-stage homogenization with two homogenizer heads in series. This method has become more widely used when it has been found that homogenization in one stage, also under optimum conditions and with products with a low fat content, sometimes results in fat clusters. Homogenization takes place at 75% of the total pressure in the first stage and 25% in the second. At a total homogenization pressure of 200 bar this means that the pressure is 150 bar in the first stage and 50 bar in the second. Any clusters, formed in the first stage, will be broken down in the second and membranes will then be formed round the free fat.

Two-stage homogenization is nearly always used in connection with UHT treatment. The reason is that certain salts are formed during the “high-temperature treatment”. The salt particles are easily disintegrated when the product is homogenized in two stages.

6. Cultured-milk products

Cultured milk is the collective name for products such as yoghurt, ymer, kefir, cultured buttermilk, filmjölk (Scandinavian sour milk),cultured cream and koumiss. The generic name of cultured milk is derived from the fact that the milk for the product is inoculated with a starter culture which converts part of the lactose to lactic acid. Carbon dioxide, acetic acid, diacetyl, acetaldehyde and several other substances are formed in the conversion process, and these give the products their characteristic fresh taste and aroma. The microorganisms used in the production of kefir and koumiss also produce ethyl alcohol.

Cultured milk originates from the Near East and subsequently became popular in Eastern and Central Europe. The first example of cultured milk was presumably produced accidentally by the nomads. This milk "turned sour" and coagulated under the influence of certain micro-organisms. As luck would have it, the bacteria were of the harmless, acidifying type and were not toxin-producing organisms. The conversion of lactose into lactic acid has a preservative effect on the milk. The low pH of cultured milk inhibits the growth of putrefactive bacteria and other detrimental organisms. The product consequently has a very long shelf life. On the other hand, the acidified milk is a very favourable environment for yeast and moulds which will cause off-flavours if allowed to infect the milk products. The digestive systems of some people lack the lactase enzyme. As a result, the lactose will not be broken down in the digestive process into simpler types of sugars. These people cannot drink ordinary milk. They can, however, eat cultured milk, in which the lactose is already partly broken down by the bacterial enzymes.

In the production of cultured milk the best possible growth conditions must be created for the starter culture. These are achieved by heat treatment of the milk, so that any competing micro-organisms will be inhibited. In addition, the milk must be maintained at the optimum temperature for the relevant starter culture. When the best possible taste and aroma have been achieved, the cultured milk must be cooled quickly in order to stop the fermentation process. An excessively long or short fermentation time will cause impaired taste and wrong consistency.

In addition to good taste and aroma, the correct appearance and consistency are important features of cultured milk. These features are achieved by the heat treatment and homogenization of the milk. Some of the most important cultured-milk products are described below. The production technique for other products has many similarities, for example the pretreatment of the milk is the same. The process description for other products is primarily concentrated on the production stages which differ from those in yoghurt production.

Yoghurt

Of all cultured-milk products, yoghurt is the most well-known and most popular almost all over the world. The highest consumption of yoghurt is in countries around the Mediterranean, in Asia and in Central Europe. Yoghurt originates from Bulgaria, where it is known as "Yaourt". Many other countries have their own names for yoghurt. The consistency, taste and aroma vary from one district to another. In some areas yoghurt is produced in the form of a highly viscous liquid, whereas in other countries it is in the form of a softer gel. Yoghurt is also produced in frozen form as a dessert, or as a drink. The taste and aroma of yoghurt differ from those of other acidified products, and the volatile aromatic substances include small quantities of acetic acid and acetaldehyde.

Yoghurt is usually classified as follows (see Figs. 1 - 3):

- Set type yoghurt, which is filled immediately after inoculation with bulk starter and incubated in the packages.
- Stirred type yoghurt, which is inoculated and incubated in a tank. After incubation the product is cooled before filling.

- Drink type yoghurt, which is based on the stirred type. The coagulum is broken down to a liquid before filling.

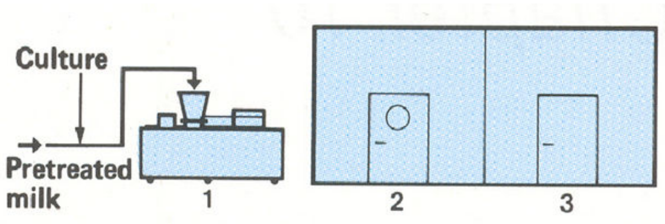


Fig. 1 Set type yoghurt (1: Filling machine; 2: Incubation room; 3:Rapid-cooling room)

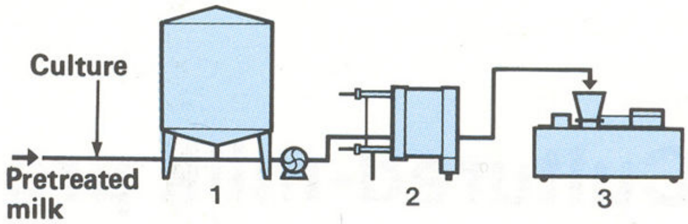


Fig. 2 Stirred type yoghurt (1:Incubation tank; 2:Cooler; 3:Filling machine)

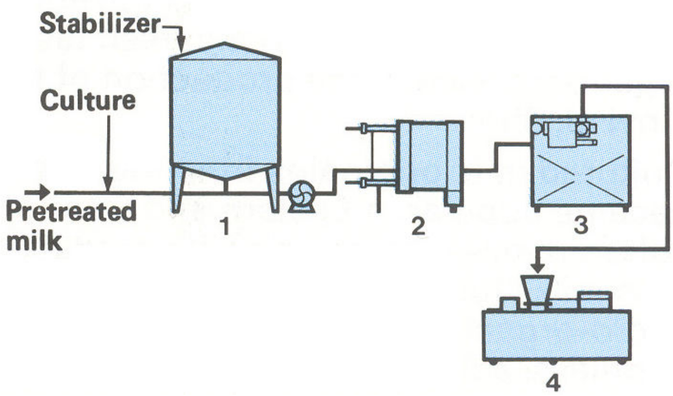


Fig. 3 Drink type yoghurt (1:Incubation tank; 2:Coler; 3:Homogenizer; 4:Filling machine)

Flavoured yoghurt

Yoghurt with various flavouring and aroma additives is very popular, although the trend back towards natural yoghurt is clearly discernible on some markets. Common additives are fruit and berries in syrup, processed or as a purée. The proportion of fruit is usually about 15%. Yoghurt is sometimes also flavoured with various essences, such as vanilla, coffee, etc. Colouring and sugar, in the form of sucrose or glucose, are sometimes added together with the flavouring. Stabilizers are also added in order to modify the consistency.
The additives increase the DS content of the finished yoghurt and a typical composition of fruit yoghurt may be:

- Fat, 1.5%
- Lactose, 3 - 4.5%
- Solids-non-fat (SNF), 11 -14%

- Stabilizer, 0.3 - 0.5%
- Total DS content, 12 - 16%

Factors affecting the quality of the yoghurt

Numerous factors must be carefully controlled during the manufacturing process in order to produce a high-quality yoghurt with the required taste, aroma, viscosity, consistency, appearance, freedom from whey separation and long shelf life:

- Choice of milk
- Milk standardization
- Milk additives which improve the viscosity and texture
- Homogenization
- Heat treatment
- Culture preparation

The mechanical treatment to which yoghurt is subjected during production also has got an effect on the quality. The design of the process line is therefore very important to the quality.
The pretreatment of the milk and culture preparation are the same, regardless of whether set type or stirred type yoghurt is to be produced.

Pretreatment of the milk
Pretreatment of the milk includes a number of measures, ali very important to the quality of the finished product.

Choice of raw material
The milk for yoghurt production must be of the highest bacteriological quality. It must have a low content of bacteria and substances which may impede the development of the yoghurt culture. The milk must not contain penicillin, bacteriophages, residues of CIP solution or sterilizing agents. The dairy should therefore obtain the milk for yoghurt production from selected, approved producers. The milk must be very carefully analysed at the dairy.

Standardization of the milk
The fat and dry solids contents of the milk are standardized.

Fat content
Yoghurt may have a fat content of 0.5 to 3.0% and can be classified in the following groups, according to the FAO/WHO code and principles:

- Yoghurt
  Min. fat content 3.0%
- Partially skimmed yoghurt
  Max. milk fat less than 3.0%
  Min. milk fat more than 0.5%
- Skimmed yoghurt
  Max. milk fat 0.5%

DS content

According to the FAO/WHO code and principles the minimum milk SNF is 8.2%. An increase in the total DS content, particularly the proportion of casein and whey protein, will result in a firmer yoghurt coagulum, and the tendency to whey separation will then be reduced. At present the DS content is standardized by means of:

o evaporation. 10 - 20% of the water in the milk is normally evaporated. This corresponds to an increase of 1 - 2.3% in the DS content

o addition of milk concentrate

o addition of skim milk powder, usually 0.5 - 2.5%

Milk additives

Stabilizers and sweeteners may be used as additives in yoghurt production. Vitamins, usually vitamin C, are sometimes also added.

Stabilizers

Hydrophilic colloids can bind water. They increase the viscosity and contribute to the prevention of whey separation in yoghurt. The type of stabilizer and the rate at which it should be added must be determined experimentally by each manufacturer. The product may acquire a rubbery, hard consistency if the wrong stabilizer, or an excess of stabilizer, is used.

Correctly produced, natural yoghurt requires no addition of stabilizers, as a firm, fine gel with a high viscosity will occur naturally. Stabilizers can be used in fruit yoghurts and must be used in pasteurized yoghurt. Stabilizers (0.1 - 0.5%), such as gelatine, pectin and agar-agar, are normally added.

During certain seasons of the year, the ability of milk to coagulate may be reduced due to a deficiency of positive ions in the milk. This applies particularly to calcium ions. A "salt stabilizer" (0.02 - 0.04%) in the form of calcium chloride ($CaCl_2$) is therefore added.

Sweeteners

Sweeteners, in the form of sucrose or glucose, can be added to fruit yoghurt. The fruit contains about 50% sugar and this normally makes up for the entire sugar content. Small quantities of sweetener can also be added in the production of natural yoghurt.

Homogenization

The stability and consistency of yoghurt are improved by homogenization of the milk. The firmness of the gel increases with increasing homogenization pressure, if all the milk is treated. Yoghurt milk should be homogenized at about 20 MPa (200 bar) at a temperature of 55 - 70 °C.

Apart from improving the stability and consistency, homogenization also gives more "body" to the yoghurt. This is due to the fact that fat is prevented from separating.

Heat treatment

The milk is heat treated before being inoculated with the starter in order to:

- improve the properties of the milk as a substrate for the bacteria of the bulk starter,
- ensure that the coagulum of the finished yoghurt will be firm,
- reduce whey separation in the finished product.

Optimum results are achieved by heat treatment of the milk at 90-95 °C and a holding time of 5 minutes. The whey proteins are denatured and consequently contribute to the stability of the yoghurt "body".

Manufacture of the culture

The manufacture of the starter for yoghurt production demands maximum accuracy and hygiene. The aseptic process lines, described in the chapter "Cultures and starter manufacture", are generally used in the production.

The bacteria used are strains of the Streptococcus tbermophilus and Lactobacillus bulgaricus. The culture originally used for yoghurt also contained other types of α-lactose fermenting organisms, although these cultures are now considered to be contaminated.

The ratio of cocci to bacilli, in the culture and in the yoghurt, is usually about 1:1 or 2:1. However, the balance can easily be disturbed unless all variables, such as inoculation quantities, times and temperatures, are kept under strict control. The cultures must be replaced at regular intervals, as repeated transfer will change the ratio. Lactobacillus bulgaricus will then of ten dominate, and this will result in a sharp taste, as excessive acid and acetaldehyde are formed.

Aseptic production of the starter eliminates the risk of infection by bacteria, yeast and moulds. In conventional starter manufacture the culture can be infected by spore-forming bacteria. These are heat-resistant and often survive the heat treatment of the milk. They give a bitter taste and aroma to the yoghurt.

Immediately after production, yoghurt should have an acid content of between 0.9 and 1.0%. The acidity may then increase slightly during distribution. The pH is usually between 4.4 and 4.2, but values as low as 4.0 do occur. The acid content can be regulated by means of accurately controlled incubation of the culture with L. bulgaricus and Str. thermophilus and rapid cooling of the product at optimum pH. A high acid content is usually accompanied by higher contents of aromatic and flavouring substances.

Production lines

The pretreatment of the milk is the same, regardless of whether set type or stirred type yoghurt is to be produced, and the treatment includes standardization of the fat and DS contents, heat treatment and homogenization.

Fig. 5 shows an example of the design of a process line for milk for yoghurt production. The milk storage tanks, from which the milk is pumped to the process line, are not included in the figure.

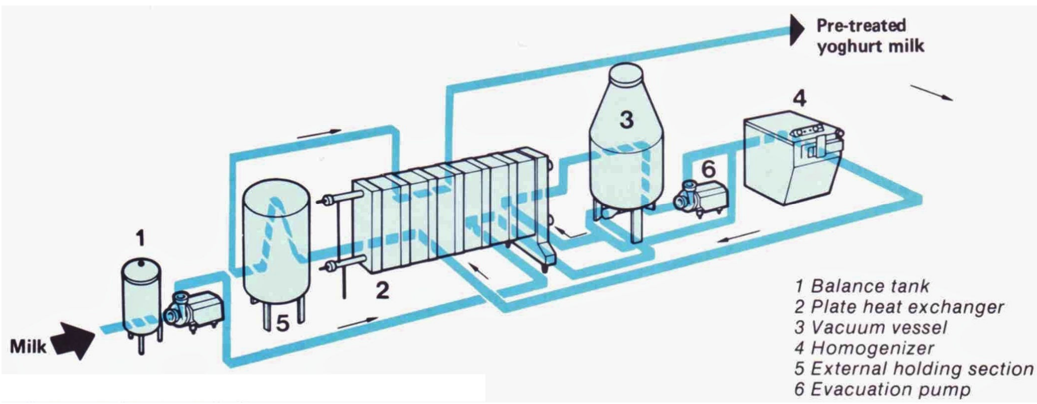


Fig. 5 Arrangement of yoghurt milk treatment line

It is assumed that the milk has been standardized to the required fat content when it is admitted into the line. In the example, standardization of the DS content takes place in an evaporator in the process line. If the DS is adjusted by the addition of milk powder, the equipment used is similar to that described under "Recombination of milk".

Any additives, such as stabilizers, vitamins, etc., can be proportioned into the milk before the heat treatment. From the balance tank the milk is pumped to heat exchanger 2, where it is first preheated regeneratively to about 70 °C and then heated to 90 °C in the second section.

Evaporation

From the heat exchanger the hot milk flows to vacuum vessel 3, where 10 - 20% of the water in the milk is evaporated. The proportion depends on the required DS content of the milk. If 1020% of the milk is evaporated, the total DS content will be increased by about 1.0 - 2.3%. The degree of evaporation is controlled by the temperature of the milk at the inlet to the vacuum vessel, the circulation rate through the tank and the vacuum in the vessel. Some of the water evaporated from the product is used to preheat the incoming milk. This improves the thermal economy of the plant.
A certain amount of milk must be recirculated through the vacuum vessel in order to obtain the desired degree of evaporation. Each passage evaporates 3 - 4% water, so, in order to obtain 15% evaporation, the recirculated flow must be four to five times the capacity of the pasteurizer. The milk temperature drops from 90 °C to about 70 °C during evaporation.
The evaporation equipment described is designed for capacities up to about 8 000 l/h. Larger evaporators, of the falling-film type, are used for higher capacities - up to 30 000 l/h.

Homogenization

After evaporation the milk continues to homogenizer 4 and is homogenized in one stage at a pressure of approx. 20 MPa (200 bar). Homogenization takes place in a homogenization head in a homogenizer.

Pasteurization

The homogenized milk flows back through the regenerative section to the pasteurization section of heat exchanger 2 and is reheated to 90 - 95 °C. The milk then flows to a holding section with a holding time of 5 minutes. Other time/temperature programs can be used. The pasteurization efficiency in the holding section is 90 - 95%, which is appreciably higher than in a holding tank.

Cooling of the milk

After pasteurization, the milk is first cooled in a regenerative section, and then by means of water to an inoculation temperature of 40-45 °C.

Design of the yoghurt plant

When the yoghurt milk has been pretreated and cooled to the inoculation temperature, the procedure for the further treatment depends on whether set type, stirred type or drink type yoghurt is to be produced. The block diagram in Fig. 6 shows the various production stages for each process.

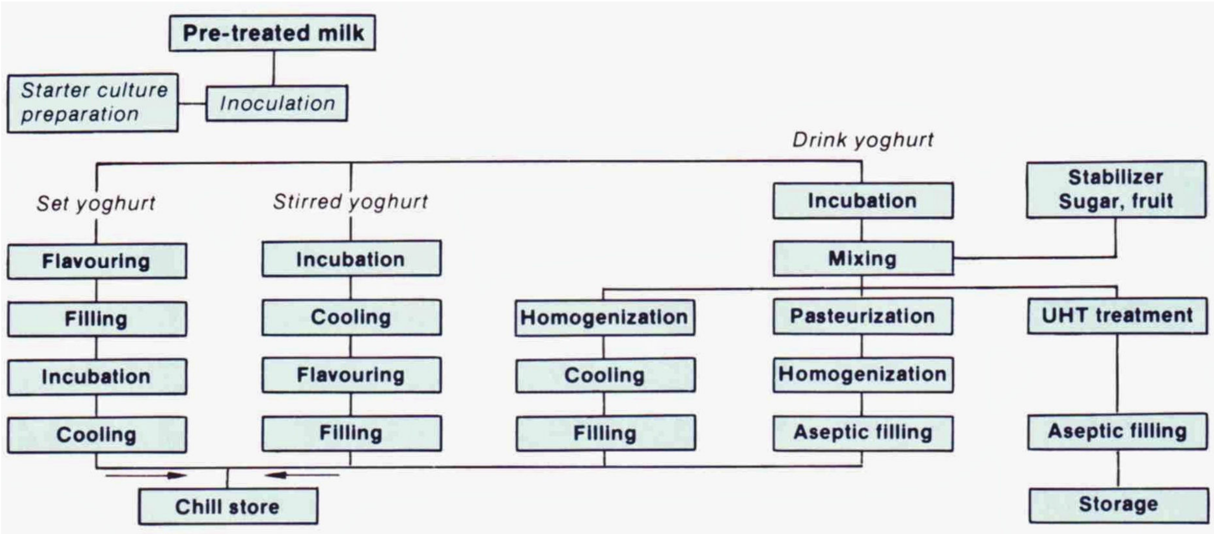


Fig. 6.The stages in the production of the different types of yoghurt

The quality of the yoghurt in terms of texture and taste depends on the design of the plant, the treatment of the milk and the treatment of the product. Today the plants are designed to satisfy the demands on high production, continuous treatment and high quality. The level of automation varies, and complete CIP systems are normally integrated into the plant.

The level of automation is usually high in large-scale production. Excessive mechanical treatment of the product must be avoided, as it may cause product defects such as a thin consistency and whey separation (syneresis). The total volume of treatment to which the product is subjected must be taken into consideration when the plant is designed. The choice of suitable equipment and the matching and optimization of the plant are consequently a question of achieving a suitable balance between cost and quality.

In modern plants, stirred and set types of yoghurt are often produced concurrently. In the production of set type yoghurt the product flow is continuously controlled from the point when the milk is accepted in the pretreatment section to the filling of the product. In the production of stirred type yoghurt, the pretreatment of the milk is continuous up to the point at which it is pumped into the incubation tanks, to which the bulk starter is added. The continuity is interrupted by the time-consuming incubation, which must not be subjected to any physical disturbance.

Stirred type yoghurt

A typical plant for production of stirred type yoghurt is shown in Fig..7

The pretreated milk, cooled to incubation temperature, is pumped to one of the incubation tanks, 7. The required amount of bulk starter is proportioned by a metering pump when the tank has been filled. An agitator distributes the starter in the tank. After inoculation, agitation continues for a few minutes in order to ensure that the starter is thoroughly mixed into the milk.

The incubation tanks are insulated in order to ensure that the temperature remains constant during the incubation period. The tank can be fitted with a pH meter in order to check the development of acid.

Cooling of the gel

In the final stage of the incubation, when the required pH (normally about 4.2 - 4.5) has been reached, the temperature must be reduced rapidly to 12 - 15 °C. This retards further increase in acidity. At the same time the gel must be subjected to gentle mechanical treatment so that the final product will have the correct consistency.

Cooling takes place in plate heat exchanger 8. This ensures gentle mechanical treatment of the product. The capacities of pump and cooler are dimensioned to empty a tank in 20 - 30 minutes in

order to maintain a uniform product quality.
The cooled yoghurt is pumped to buffer tanks 9 in order for the production rate to be independent of the capacity of filling machines 11.
In order to ensure a continuous flow of yoghurt to the filling machines, the filling capacity must match the pretreatment capacity and a number of incubation tanks must be used. 4 or 5 incubation tanks are sufficient when the volume of a tank is the same as the pretreatment capacity per hour.

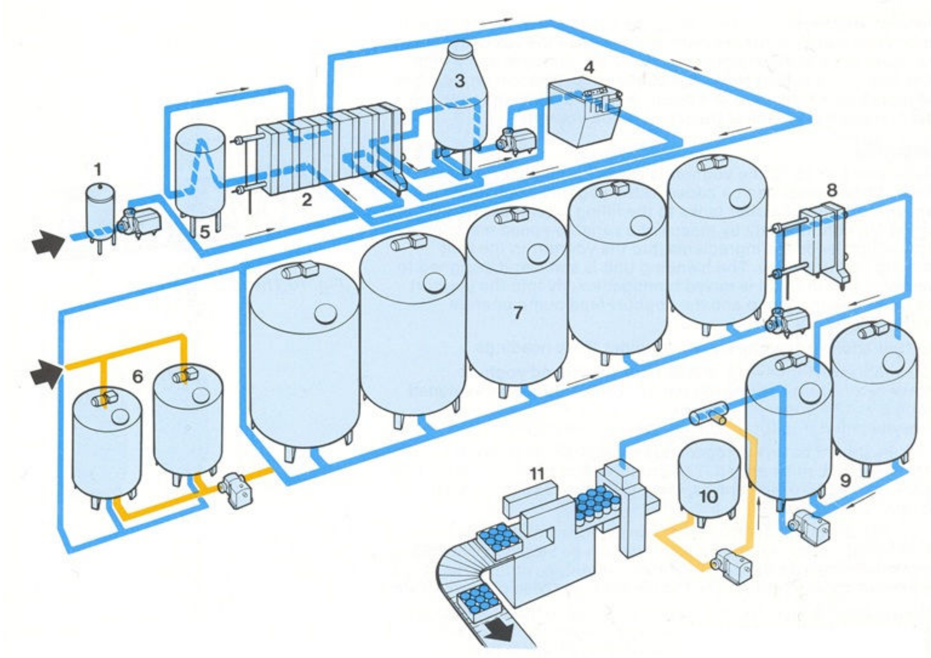


Fig. 7 Production line of stirred type yoghurt

The yoghurt coagulum is broken by the treatment in the pump and cooler. The mechanical treatment will decrease the viscosity, but in a well-designed plant the yoghurt viscosity will increase again after some hours in a chilled store. It is vitally important that tanks, pipes and plate heat exchangers are designed with consideration to the total permitted mechanical treatment of the yoghurt.

Flavouring
After cooling to 15 °C the yoghurt is ready for filling. Fruit and different flavourings can be added to the yoghurt when it is transferred from the buffer tanks to the filling machines. This is carried out continuously by means of a variable-speed metering pump which feeds the ingredients into the yoghurt in the fruit blending unit. The blending unit is static and designed to guarantee that the fruit is mixed homogeneously into the yoghurt. The fruit metering pump and the yoghurt feed pump operate synchronously.
The fruit additives can be classified under three headings:

- 5 - 15% sweetened fruit, added to unsweetened yoghurt,
- unsweetened fruit added to yoghurt which has been sweetened with 8 - 12% sugar,
- unsweetened fruit for producing low-calorie yoghurt.

The fruit should be as homogeneous as possible. A thickener in the form of pectin can be added. The proportion of pectin is hardly ever higher than 0.5%, which corresponds to 0.05 - 0.005% of pectin in the finished yoghurt. A concentrate of natural fruit juice can be added to give the yoghurt the required colour. Aroma concentrate can be added in order to reconstitute the fruit flavour. This also guarantees uniform taste - in the case of apple yoghurt even if different types of apples are used. Pasteurization is an extremely important stage in the pretreatment of fruit additives. Scraped-surface heat exchangers, or tanks with scraper units, can be used for pasteurization of whole berries or fruit with solid particles. The temperature program should be such that all vegetative micro-organisms will be inactivated, without impairing the taste and structure of the fruit. Continuous production, with rapid heating and cooling, is therefore important with regard to product quality and economic aspects.

Filling

Filling of yoghurt takes place in various types of filling machines. The sizes of the packages vary from one market to another.

Set type yoghurt

The process line for set type yoghurt is similar as a stirred type having some differences. In a modern plant, the trend is towards making the entire production process continuous - from the milk being pumped into the pretreatment line to the product leaving the chilled store. The number and capacities of the filling machines decide the capacity of the plant. The yoghurt milk, which has been cooled to inoculation temperature in the pretreatment line, is transferred to insulated buffer tanks. These can hold the production of pretreated milk in the event of temporary stoppages of the filling machines.

Inoculation

From buffer tanks, milk is pumped to the filling machines by means of a positive displacement pump. At the same time the required proportion of bulk starter is continuously metered into the flow from the buffer tanks by a positive displacement pump. The operation of this pump is synchronized with that of the milk pump so that the correct amount of starter is always metered into the milk.

Flavouring

Concentrates of fruit, chocolate, coffee, etc. are added to flavoured set type yoghurt. If highly acid fruit concentrates are added, the pH of the milk may became reduced so that the development of the streptococci is inhibited. This increase in acidity must be neutralized in order to prevent changes in the bacteria flora.
Flavouring additives are metered in the same way as for the stirred type yoghurt, or directly into the packages immediately before the metering of yoghurt milk.

Filling and incubation

After any required inoculation and flavouring the milk is filled in consumer packages. These are placed in crates which are stacked on pallets and immediately transferred to the incubation rooms. Incubation takes place at 41-44 °C for 3 - 4 hours and the fermentation process is carefully monitored during this period. Samples are collected from each pallet for analysis of the pH in the laboratory. Provisions must be made for accurate temperature control in the incubation room. The incubation is interrupted by cooling when the pH is about 4.5.
The filling machine must provide completely hygienic and accurate volumetric filling, and the package must be tightly sealed. The machine should be designed for continuous operation. In addition, the filling station and other equipment in the line must be designed for connection to a CIP system.

Cooling

When the correct pH has been reached during incubation, any further reduction is stopped by the pallets being carefully transported to a cooling tunnel, where the product is cooled to 10 - 15 °C. The tunnel has a conveyor with a speed which passes the pallet through the tunnel in 1 - 1.5 hours. From the cooling tunnel the product continues to the chilled store for further cooling to about 4 °C. It is important that the pallets are transported very carefully so that the coagulum will not become damaged.

Drink type yoghurt

In many countries a low-viscosity, drinkable yoghurt, normally with a law fat content, is popular. Different process lines for drink type yoghurt are shown in Fig. 8.

The pretreated milk, cooled to incubation temperature, is pumped to one of the incubation tanks. The required amount of bulk starter is added and mixed with the milk. After incubation the coagulum is broken up with an agitator and mixed with fruit juice, sugar and stabilizer. The yoghurt mix can then be treated in different ways, depending on the required shelf life of the product:

- homogenized and cooled if a shelf life of 2 - 3 weeks is required,
- homogenized, pasteurized and aseptically filled if a shelf life of more than one month is required,
- homogenized, UHT treated and aseptically filled for a shelf life of several months at room temperature.

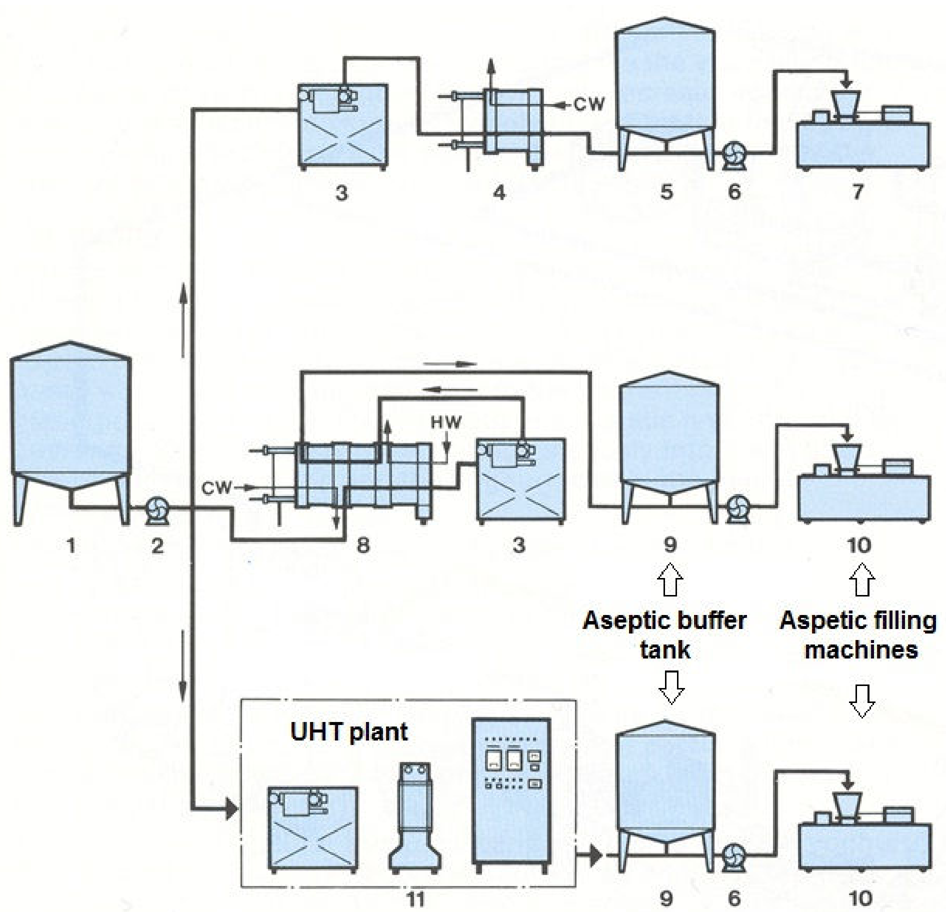


Fig. 8 Process line for drink type yoghurts

7. Butter

Butter is basicaily the fat in the milk and is usually divided into two main categories:

- sweet cream butter
- acidified or soured cream butter made from bacteriologically
- soured cream

Butter may also be classified according to the salt content: unsalted, salted and extra salted.
Weil into the 19th century butter was still made from cream that had been allowed to sour naturally. The cream was then skimmed from the top of the milk and poured into a wooden tub. Buttermaking was carried out by hand in butter churns. The natural souring process is very sensitive and infection by foreign micro-organisms often spoiled the result.
As knowledge of cooling increased it became possible to skim the cream, before it had gone sour, and make butter from the sweet cream. Buttermaking methods gradually improved, and so did the product quality and economic yield. It was eventually found that sweet cream could be soured by the addition of naturally soured milk or acid buttermilk. It then became possible to make ripened cream butter under more controlled conditions.
The invention of the separator (1878) meant that the cream could be skimmed from the milk quickly and efficiently. It was also the start of large-scale buttermaking. Contributions to the quality of the product and buttermaking economics were also made by the introduction of pasteurization in the 1880's, the use of pure bacteria cultures in the 1890's and the introduction of the buttermaking machine at the turn of the century.
Today's commercial buttermaking is a product of knowledge and experience gained over the years about such matters as hygiene, bacterial acidifying and temperature treatment, as well as the rapid technical development that has resulted in the advanced machines now used.

Sweet and soured cream butter
The principal constituents of normal salted butter are fat (80 - 82%), water (15.6 -17.6%), salt (about 1.2%) and protein, calcium and phosphorous (about 1.2%). Butter also contains fat-soluble vitamins A, D and E (tocopherol).
Butter should have a uniform colour, be dense and taste fresh. The water content should be dispersed in fine droplets so that the butter looks dry. The consistency should be smooth so that the butter is easy to spread and melts readily in the mouth. Soured cream butter should smell of diacetyl while sweet butter should taste of cream - a faint "cooked" flavour is acceptable' in the case of sweet butter.
Butter made from soured cream has certain advantages over the sweet cream variety. The aroma is richer, the butter yield higher and there is less risk of reinfection after temperature treatment as the bacteria culture suppresses undesirable micro-organisms.

Soured cream butter also has its drawbacks. Buttermilk is also acidified. Buttermilk from soured cream butter has a far lower pH value than buttermilk from sweet cream butter. Sometimes it is more difficult to dispose of than buttermilk from sweet cream butter. Another disadvantage of ripened cream butter is that it is more sensitive to oxidation defects, resulting in a metallic taste. This tendency is accentuated if the slightest trace of copper, or other heavy metals, is present, and this reduces the chemical keeping properties of the butter considerably.
In the manufacture of acidified butter the greater part of the metal ions will be entrained with the fat phase and make the butter prone to oxidation. In processing sweet cream butter most of the metal

ions are drained off together with the buttermilk and the risk of oxidation defects is therefore reduced.

Buttermaking

The buttermaking process involves quite a number of stages. Fig. 1 schematically shows both batch production in churns and continuous production in a buttermaking machine. The churn is still used, but is rapidly becoming replaced by the continuous buttermaking machine. The different process stages in butter manufacture are:

1 Milk reception
2 Preheating
3 Fat separation
4 Cream pasteurization
5 Vacuum deaeration (if necessary)
6 Cream souring and ripening (if included)
7 Temperature treatment
8 Churning/working
9.Packaging
10. Chilling

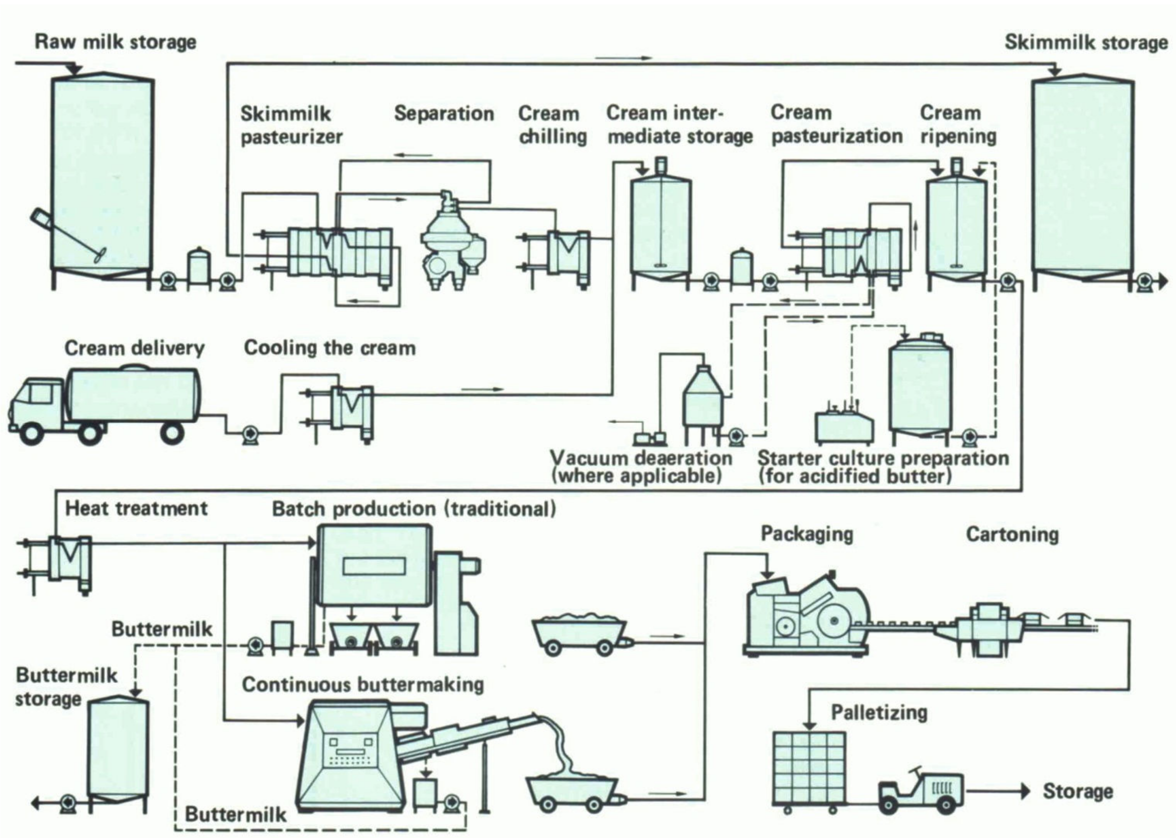


Fig. 1. Flowchart of buttermaking

The cream can be supplied by a liquid-milk dairy or separated from whole milk at the creamery. In the former case, the cream should have been pasteurized at the supplier's. Storage and delivery to the creamery should be undertaken in su ch a way that reinfection. aeration or foaming do not take place. After reception procedures, weighing-in and analysis, the cream is stored in tanks.

If the cream is separated at the creamery, the whole milk is preheated to the required temperature in a skimmilk pasteurizer before being separated. The cream is cooled and pumped to a storage tank. The skimmilk from the separator is pasteurized and cooled before being pumped to storage.
From the intermediate storage tan ks the cream continues to pasteurization at a temperature of 95 °C or more. The high temperature is needed to destroy enzymes and micro-organisms that would impair the keeping quality of the butter.
The destruction of unwanted micro-organisms is also beneficial in the case of soured cream butter, as this creates perfect growth conditions for the bacteria culture. The heat treatment also reduces the risk of oxidation.
Vacuum deaeration can also be included in the line if the cream has an undesirable flavour or aroma, e.g. onion taste. Any flavouring will be bound in the fat and transmitted to the butter unless removed. Vacuum treatment before pasteurization involves preheating the cream to the required temperature and then subjecting it to flash cooling in order to free any entrapped gas and volatile substances. After this the cream is returned to the pasteurizer for further treatment - heating, holding and cooling - before proceeding to the ripening tank. Investigations imply that vacuum deaeration has an unfavourable effect on the consistency of the butter and on the yield. It is therefore better if it is possible to avoid this treatment.
In the ripening tank the cream is subjected to a temperature program which will give the fat the required crystalline structure when it solidifies during cooling. The program is selected to agree with factors such as the composition of the butterfat, expressed, for example. in terms of the iodine value which is a measure of the unsaturated fat content. The treatment can also be modified to produce butter with good consistency despite a low iodine value, e.g. when the unsaturated proportion of the fat is low.
Ripening usually takes 12 -15 hours. Where possible, the acid producing bacteria culture is added before the temperature treatment. The quantity of culture added depends on the treatment program selected regarding the iodine value.
From the ripening tank the cream is pumped to the continuous buttermaker or the churn via a plate heat exchanger, which brings it to the required temperature. In the churning process the cream is agitated violently in order to break down the fat globules, causing the fat to coagulate into butter grains. The fat content of the remaining liquid, the buttermilk, decreases.
The cream is split into two fractions: butter grains and buttermilk. In traditional churning the machine stops when the grains have reached a certain size, and then the buttermilk is drained off. The buttermilk is continuously drained from the continuous buttermaking machine. After draining, the butter is worked to a continuous fat phase containing a finely dispersed water phase. It used to be common practice to wash the butter after churning in order to remove any residual buttermilk and mi lk solids, but this is rarely the case today. If the butter is to be salted, salt is spread over the butter surface, in batch production. In continuous buttermaking a salt slurry is added to the butter during the working stage.
After salting, the butter must be worked vigorously in order to ensure an even distribution of the salt. The working of the butter also affects the characteristics by which the product is judged - aroma, taste, keeping quality, appearance and colour. The finished butter is discharged into the packaging unit and from there to cold storage.

The raw material

The cream must be of good bacteriological quality, without taste or aroma defects. The iodine value is the deciding factor in the selection of manufacturing parameters. Unless corrected, fat with a high iodine value (high unsaturated fat content) will produce greasy butter. Butter of acceptable consistency can be obtained from both hard fat (iodine value down to 28) and soft fat (iodine value up to 42) by varying the ripening treatment to suit the iodine value.

Cream containing antibiotics or disinfectants is unsuitable for the manufacture of acidified butter. If harmful micro-organisms have been given the chance to develop, the cream can not be used, even if they can be rendered inactive by heat treatment. Strict hygiene is therefore essential in ali stages of the production process.

A problem in countries with a refrigerated distribution chain is that the cold storage has resulted in changes in the micro-organic composition. Where lactic-acid bacteria once dominated there are now bacteria strains that have a high resistance to cold - the psychrotrophic bacteria. These are normally destroyed during pasteurization and have therefore no effect on the quality of the butter. Some psychrotrophic bacteria strains, however, produce lipolytic enzymes which can break down the fat. They can withstand temperatures above 100 °C. It is consequently vital that psychrotrophic bacteria development is prevented. One solution is chilling the raw material to 2 - 4 °C immediately on arrival at the dairy and storage at this temperature until pasteurization. Pasteurization should take place as soon as possible and definitely not later than 24 hours after arrival.

Pasteurization

Cream is pasteurized at a high temperature, usually 95 °C or higher. The heat treatment should be sufficient to result in a negative peroxidase test. This vigorous treatment kills not only pathogenic bacteria but also other bacteria and enzymes that could affect keeping quality. The heat treatment should not be so intense that there will be defects, such as a cooked flavour.

Vacuum deaeration

If necessary, any undesirable flavouring substances of a volatile nature can be removed by vacuum treatment. The cream is first heated to 78 °C and then pumped to a vacuum chamber where the pressure corresponds to a boiling temperature of 62 °C. The reduced pressure causes volatile flavouring and aromatic matter to escape in the form of gas when the cream is flash cooled. After this treatment the cream is returned to the heat exchanger for pasteurization and cooling, and then continues to the ripening tank.

Onion off-flavour is a very common defect during the summer when various on ion plants grow in the fields. Sorting of the cream is sometimes necessary in order to avoid strong flavours.

Bacterial souring

Bacteria cultures for the manufacture of acidified or soured cream butter are produced as described in the chapter "Cultures and starter manufacture". The addition of acid-producing bacteria gives the butter a strong aroma. It also improves the fat yield. Starter cultures are of the DL or L type. They contain the acidproducing bacteria Str. diacetilactis and Leuc. citrovorum or only Leuc. citrovorum. In DL acids the proportion of Str. diacetilactis can vary between 0.6 and 13% whilst the Leuc. citrovorum content varies from 0.3 to 5.9% of the total bacteria count. The proportional relationship between the aroma producers is governed by growth conditions in the dairy. Citric acid, diacetyl and acetic acid are the most important of the aroma substances produced by bacteria. The production of the most important of the aromatics in butter, diacetyl, is dependent on the availability of oxygen.

The amount of bulk starter to be added to the cream must be decided on the basis of the temperature program for the process. It must be proportioned to suit the acidifying and ripening temperatures as well as the duration of the different phases. Bulk starter dosage can vary from 1 to 7% of the amount of cream. The lower figure applies to cream with hard fat (low iodine value) and the higher to cream with soft fat. The souring process should be completed when the temperature treatment is finished and the cream continues to churning. The acidity of the non-fat part of the cream should then be about 36 °SH.

Temperature treatment

Before churning, the cream is subjected to a program of temperature treatment, which will control the crystallization of the fat so that the butter will have the desired consistency. The consistency of the butter is one of its most important quality characteristics, both directly and indirectly, as it affects the other characteristics - mainly taste and aroma. Consistency is a complicated concept and involves properties such as hardness, viscosity, plasticity and spreading ability.

The fatty acids in milk fat have been described in the chapter "The chemistry of milk". The relative amounts of fatty acids with high melting points determine whether the fat will be hard or soft. Soft fat has a high content of low-melting fatty acids and at room temperature this fat has a large continuous phase of liquid fat - the ratio liquid/solid fat is high. On the other hand, in a hard fat the solid phase of high-melting fat is larger than the continuous liquid-fat phase - the ratio of liquid/solid fat is low.

In buttermaking, if the cream is always subjected to the same temperature treatment, it will be the chemical composition of the milk fat that determines the consistency of the butter. Soft milk fat will result in soft and greasy butter, whereas butter from hard milk fat will be hard and stiff. The consistency of the butter can be optimized if the temperature treatment is modified to suit the iodine value of the fat. The temperature treatment regulates the amount of solid fat to a certain extent - this is the major factor that determines the consistency of the butter.

Butterfat crystallization

The fat in the fat globules is in liquid form after pasteurization. When the cream is cooled to below 40 °C the fat starts to crystallize. If the cooling is gradual, the different fats will crystallize at different temperatures, depending on their melting points. The fat crystals would then be "pure" - each crystal would contain triglycerids with the same melting point. This would be an advantage as this type of cooling would result in a minimum of solid fat - a soft butter could then be made from cream containing hard milk fat with low iodine values.

The formation of crystals is very slow during gradual cooling and the crystallization process takes several days. This would be dangerous from a bacteriological point of view as the fat would be kept at temperatures favourable for bacterial attacks. It would also be impractical for economical reasons.

A method of speeding up the crystallization process is quick cooling of the cream to a low temperature, where the formation of crystals is very rapid. The drawback with this method is that triglycerids with different melting points will be "trapped" in the same crystals and so called mixed crystals will form. A great proportion of the fat would be crystallized if no measures were taken. The ratio of liquid/solid fat would be low and the butter made from this cream would be hard. This can be avoided if the cream is heated carefully to a higher temperature in order to melt the triglycerids with a higher melting point from the crystals. The melted fat is then recrystallized at a slightly lower temperature, resulting in a higher proportion of "pure" crystals and a lower proportion of mixed crystals. A higher liquid/solids ratio and a softer fat will consequently be obtained.

It is obvious that the amount of mixed crystals, and thereby the ratio of liquid/solid fat, can be determined to a certain degree by selecting the heating temperature at which the fat crystals are melted after cooling and crystallization and also the recrystallization temperature. The temperatures are selected according to the hardness of the fat the iodine value. Today there are several methods available for measuring the ratio of liquid/solid fat in a fat sample. The NMR pulse spectrometer test is a very fast and accurate method. This technique is based on the fact that the protons (the hydrogen nuclei) in the fat have different
magnetic properties, depending on whether the tat is in a liquid or a solid state. It takes about 6 seconds to analyse a fat sample using this method.
Table 1 gives examples of programs for different iodine values. The first temperature is the value to which the cream is cooled after pasteurization, the second the heating/souring value and the third the ripening value.

Treatment of hard fat

For optimum consistency, when the iodine value is low, i.e. the butterfat is hard, the amount of mixed crystals must be minimized and the amount of "pure" fat maximized in order to increase the ratio of liquid/solid fat in the cream. The liquid-fat phase in the fat globules
will then be maximized and much of it can be pressed out during churning and working, resulting in butter with a relatively large continuous phase of liquid fat and with a minimized solid phase.

The treatment necessary to achieve this result comprises the following stages:

- Rapid cooling to about 8 °C and storage for about 2 hours at this temperature.
- Heating gently to 20 – 21°C and storage at this temperature for at least 2 hours. Water at max. 27 °C is used for heating.
- Cooling to about 16 °C and then to churning temperature.

Cooling to about 8 °C starts the formation of mixed crystals that bind fat from the liquid continuous phase. When the cream is heated gently to 20 – 21°C the bulk of the mixed crystals me lt, leaving only the pure crystals of fat with a low melting point. During the storage period at 20 – 21°C the melted fat begins to crystallize, forming pure crystals.
After 1 - 2 hours most of the fat with a higher melting temperature has melted and some of it has started to recrystallize. By reducing the temperature to about 16 °C, the melted fat continues to crystallize and form pure crystals. During the holding period at 16 °C, all fat with a melting point of 16 °C or higher will crystallize. The treatment has caused the high-melting fat to form pure crystals and thereby reduced the amount of mixed crystals. This increases the ratio of liquid/solid fat and the butter made from the cream will consequently be softer.

Treatment of medium-hard fat

With an increase in the iodine value the heating temperature is accordingly reduced from 20 – 21°C. A greater amount of mixed crystals will form, absorbing more liquid fat th an is the case with the hard-fat program. For iodine values up to 39 the heating temperature can be as low as 15 °C. The souring time is extended at the lower temperatures.

Treatment of very soft fat

The "summer method" of treatment is used when the iodine value is higher than 39 - 40. After pasteurization the cream is cooled to 20°C and soured for about 5 hours at this temperature. It is cooled when the acidity is about 22 °SH. The cream is cooled to about 8 °C if the iodine value is around 39 - 40, and to 6 °C if it is 41 or higher. It is generally believed that souring temperatures below 20 °C will result in a soft butter. The same applies to higher cooling temperatures after souring.

Churning

The cream is churned after the temperature treatment and, where applicable, souring takes place. Buttermaking is traditionally carried out in cylindrical, conical, cube-formed or tetrahedral churns with adjustable speed. Axial strips and dashers are fitted inside the churn. The shape, setting and size of the dashers in relation to the speed of the churn are factors that have an important effect on the end product. Modern churns have a speed range that permits selection of the most suitable working speed for any set of butter parameters. The size of churns has increased greatly in recent years. Churns of 8000 - 12000 litres' capacity or more are used in the large centralized creameries.

Before transfer to the churn the cream is stirred and the temperature adjusted. The churn is usually filled to 40 - 50% to allow space for foaming.

Butter formation

The fat globules in cream contain both crystallized fat and liquid fat (butter oil). The fat crystals have to some extent become structured so that they form a shell, although a weak one, closest to the membrane of the fat globule.

A foam of large protein bubbles forms when the cream is agitated. Being surface active. the membranes of the fat globules are drawn towards the air/water interface and the fat globules are concentrated in the foam.

When agitation continues, the bubbles become smaller as the protein gives off water, making the foam more com pact and thereby applying pressure on the fat globules. This causes a certain proportion of the liquid fat to be pressed out of the fat globules and some of the membranes to disintegrate.

The liquid fat, which also contains fat crystals, spreads out in a thin layer on the surface of the bubbles and on the fat globules. As the bubbles become increasingly dense, more liquid fat is pressed out and the foam is soon so unstable that it collapses. The fat globules coagulate into grains of butter. At first these are invisible to the naked eye but they grow increasingly larger as working continues.

Churning recovery

Churning recovery is a measure of how much of the fat in the cream that has been converted to butter. It is expressed in terms of the fat remaining in the buttermilk as a percentage of the total fat in the cream. For example, a churning recovery of 0.50 means that 0.5% of the cream fat has remained in the buttermilk and that 99.5% has been turned into butter. Churning yield is considered acceptable if the value is less than 0.70.

Working

Working takes place when the buttermilk has been drained off. The butter grains are pressed and

squeezed to remove the moisture between them. The fat globules are subjected to a high pressure and liquid fat and fat crystals are forced out. In the resulting mass of fat (eventually the continuous phase) the moisture becomes finely dispersed by the working process, which is continued until the required moisture content is obtained. The finished butter should be dry, i.e. water phase must be very finely dispersed. No water droplets should be visible to the naked eye.
Working coagulates the butter grains produced by the churning into a mass of such a structure that the moisture is retained. but prevented from coalescing. The moisture content is checked regularly during working and adjusted so that it complies with the requirements for the finished butter.

Vacuum working
Working at a reduced air pressure is a method that is frequently used today. The result is a butter that contains less air and it is therefore somewhat harder than normal. In vacuum-worked butter the air amounts to about 1 % by volume as compared with 5 - 7% for normal butter.

Continuous buttermaking

Methods of continuous buttermaking were introduced at the end of the 19th century but their application was very restricted. In the 1940's work was resumed and resulted in three different processes, ali based on the traditional methods - churning, centrifugation and concentration or emulsifying. One of the processes, based on conventional churning, was the Fritz method. This is now used predominantly in Western Europe. In machines, based on this method, butter is made in more or less the same way as by traditional methods. The butter is basically the same, except that it is somewhat matt and denser as a result of uniform and fine water dispersion.

The manufacturing process

The cream is prepared in the same way as for conventional churning before being continuously fed from the ripening tanks to the buttermaker.
A sectional view of a buttermaker is shown in Fig. 2. The cream is first fed into a double-cooled churning cylinder (1) fitted with beaters that are driven by a variable-speed motor.
Rapid conversion takes place in the cylinder and, when finished, the butter grains and buttermilk pass on to a separation section (2), also called the first working section, where the butter is separated from the buttermilk. The first washing of the butter grains takes place en route with recirculated, chilled buttermilk. The working of the butter commences in the separation section by means of a screw which also conveys it to the next stage.
When leaving the separation section the butter passes through a conical channel and a perforated plate, the squeeze-drying section (3), where any remaining buttermilk is removed. From the squeeze-drying section the butter grains continue to the second working section (4). The two working sections each have their own motor, so that they can operate at different speeds for optimum result. Normally the first screw rotates with twice the speed of the screw in the second section. Following the last working stage, salt may be added through a high-pressure injector in the injection chamber (5).

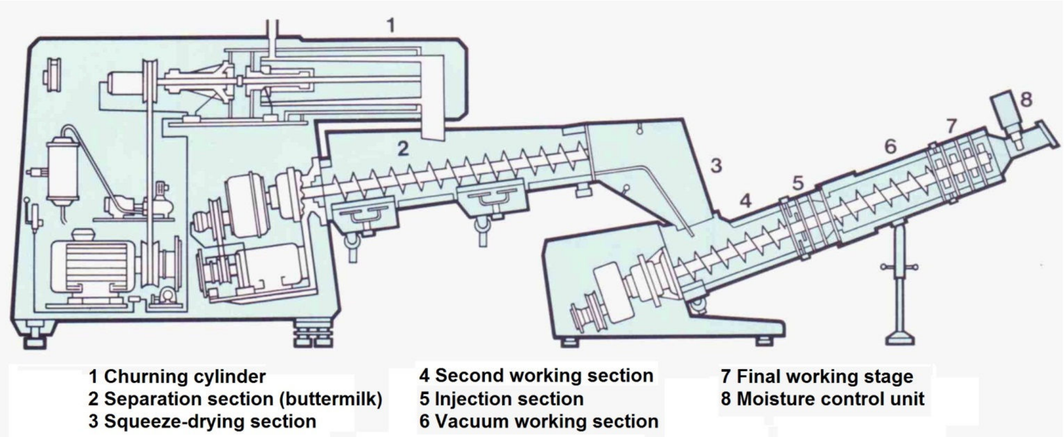


Fig. 2. Continous buttermaking machine

The next section, the vacuum working section (6), is connected to a vacuum pump. In this section it is possible to reduce the air content of the butter to the same level as for conventionally churned butter.

The final working stage (7) is made up of four small sections, each of which is separated from the adjacent one by a perforated plate. The perforation in the plates contains mesh of various diameters and working impellers of various forms, so that the butter receives satisfactory treatment. In the first of these small sections there is also an injector for final adjustment of the moisture content. Once regulated, the moisture content of the butter deviates less than ±0.1 %, provided the characteristics of the cream remain the same. Transmitters (8) for moisture content, salt content, density and temperature can be fitted in the outlet from the machine. The signals from the instruments can be used for automatic control of these parameters.

The finished butter is discharged from the end nozzle as a continuous ribbon into the butter silo for further transport to the packing machines.

Packaging

There are basically three ways of transporting the butter from the machine to packaging:

- the butter is discharged into a silo with a screw conveyor at the bottom. The conveyor feeds the butter to the packaging machine.
- the butter is pumped to the packaging machine.
- transfer by means of trolleys, often fitted with screw conveyors.

A combination of these methods is also possible. Butter is packed in bulk packages of more than 5 kg and in packets from 10 grams to 5 kg. Various types of machines are used, depending on the type of packaging. The machines are usually fully automatic, and both portioning and packaging machines can often be res et for different sizes, for example 1/2 kg and 1/4 kg or 10 and 15 g.

The wrapping material must be grease-proof and impervious to light, flavouring and aromatic substances. It should also be impermeable to moisture, otherwise the surface of the butter will dry out and the outer layers become more yellow than the rest of the butter.

Butter is usually wrapped in aluminium foil although parchment paper is still used. At one time the latter was common, but, due to the poor impermeability, has been largely replaced by aluminium foil.

After wrapping, the pat or bar packets continue to a cartoning machine for packing in card board boxes, which are subsequently loaded on pallets and transported to the cold store.

Cold storage

For the sake of consistency and appearance, butter should be placed in cold storage as soon as possible after wrapping and chilled to +5 °C for 24 - 48 hours. Unless this is done, fat crystallization is very gradual and the butter retains its freshly-churned consistency and appearance for several days. When the butter has been sufficiently chilled, a subsequent temperature increase will not make it as soft as it would have been at the same temperature prior to chilling. The initial freshly churned consistency is at the same time transformed to that typical for butter. In other words, butter cannot be considered finished until it has been chilled. A low storage temperature also improves the shelf life and reduces the risk of the packs being deformed during distribution.
Butter is essentially a perishable commodity and should not be stored longer than necessary. However, storage becomes unavoidable when production exceeds demand. Butter can be stored at about +4 °C for a short period, but must be deep-frozen at about -25 °C if it is to be stored for a longer period of time. Only best-quality butter should be deep-frozen.

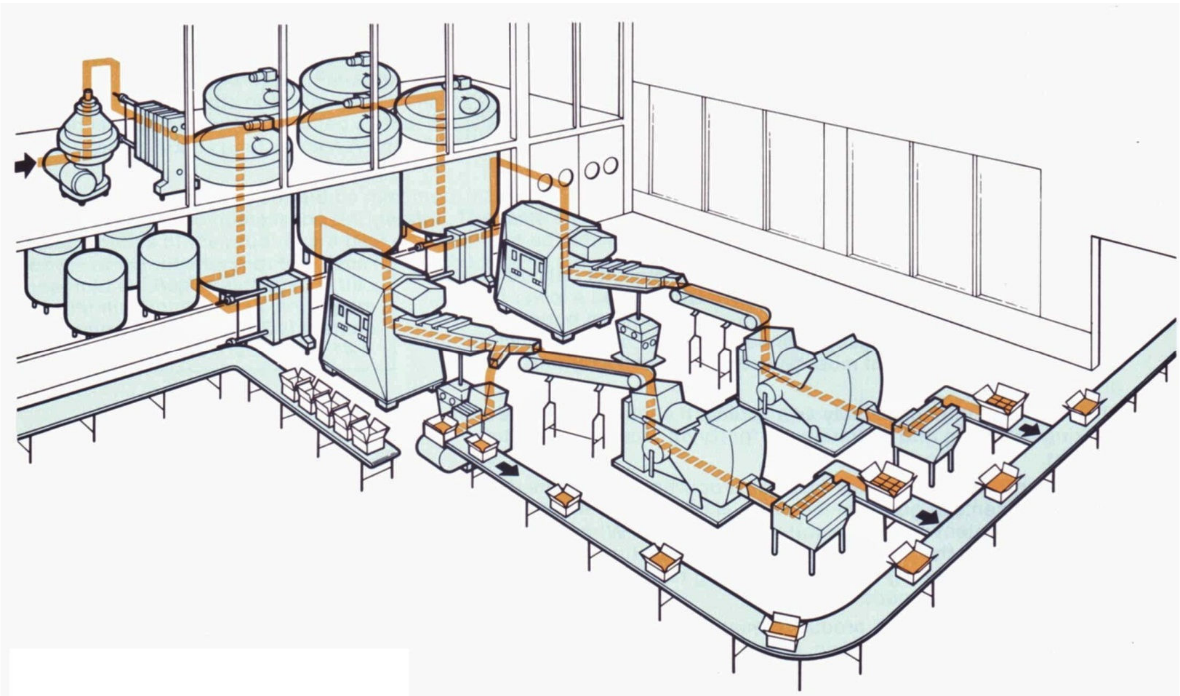


Fig. 3. Continuous buttermaking line overview

8. Cheese making

The internationally accepted definition of cheese has been formulated by FAO/WHO: Cheese is the fresh or ripened product obtained after coagulation and whey separation of milk, cream, partly skimmed milk, buttermilk or a mixture of these products.
Cheese contains protein, fat, water and salts in varying amounts, depending on the type. The possibilities of utilizing milk protein that cheese making offers have resulted in an enormous variety of cheese with different characteristics regarding flavour, solids content and shelf life. Apart from a limited production of acid-coagulated cheese, the milk for most types of cheese is coagulated with rennet and/or other proteolytic enzymes.

Cheese making involves a number of main stages which are common for all types of cheese. There are also other types of treatment which are specific in certain varieties. The main stages are illustrated schematically in Fig. 1. The cheesemilk is pretreated, possibly pre-ripened and mixed with rennet. The enzyme activity of the rennet causes the milk to coagulate to a solid gel, known as coagulum. This is cut with special cutting tools into small cubes of the desired size. During the continuation of the curdmaking process the curd grains are subjected to mechanical treatment by means of stirring tools, while at the same time the curd is heated according to a preset program. The combined mechanical and heat treatment result in syneresis (separation of a liquid - whey - from the curd grains). The finished curd is placed in cheese moulds of metal, wood or plastic, which determine the shape of the finished cheese.

The cheese is pressed, either by its own weight or by applying pressure to the moulds. The treatment during curdmaking and pressing determines the characteristics of the cheese. Gentle stirring, heating and pressing result in a soft, moist cheese with a short shelf life, whereas intensive treatment during these stages produces a hard, dry cheese that will keep for months or years.
The process flow chart in Fig. 1 also shows salting and storage. Finally, the cheese is coated, wrapped or packed.

Classification of cheese

Criteria for classification of cheese:
- *moisture content*
- *coagulation method*
- *micro-organisms used for ripening*
- *cheese texture*

It is difficult to classify all the various existing types of cheese, as there are many border-line cases. The following criteria are normally used:
- Method of coagulating casein in curdmaking; we distinguish between rennet and acid cheese. Some types of cheese are produced with both lactic acid and rennet. They are called acid rennet cheeses. Cottage cheese belongs to this category.
- Moisture content; we distinguish between hard, semi-hard and soft cheese. The moisture content is low in hard cheeses such as Parmesan, Cheddar and Emmenthal. It is much higher in soft cheeses such as Camembert and Brie.
- Principal micro-organisms used for ripening; most cheese types are ripened by means of lactic-acid bacteria. There are, however, cheese types which are also ripened by means of other micro-organisms. Tilsit, Port Salut and St. Paulin, for example, are finally ripened by micro-organisms smeared on the surfaces, blue-veined cheeses such as Roquefort and

Gorgonzola by blue moulds and Camembert by white moulds.

- Texture of the cheese; we distinguish between round-eyed, granular and close-textured cheese. The holes or eyes in cheese are formed by certain lactic-acid bacteria which, during the ripening process, develop carbon dioxide as a fermentation by-product. The carbon dioxide collects in interstices in the curd.

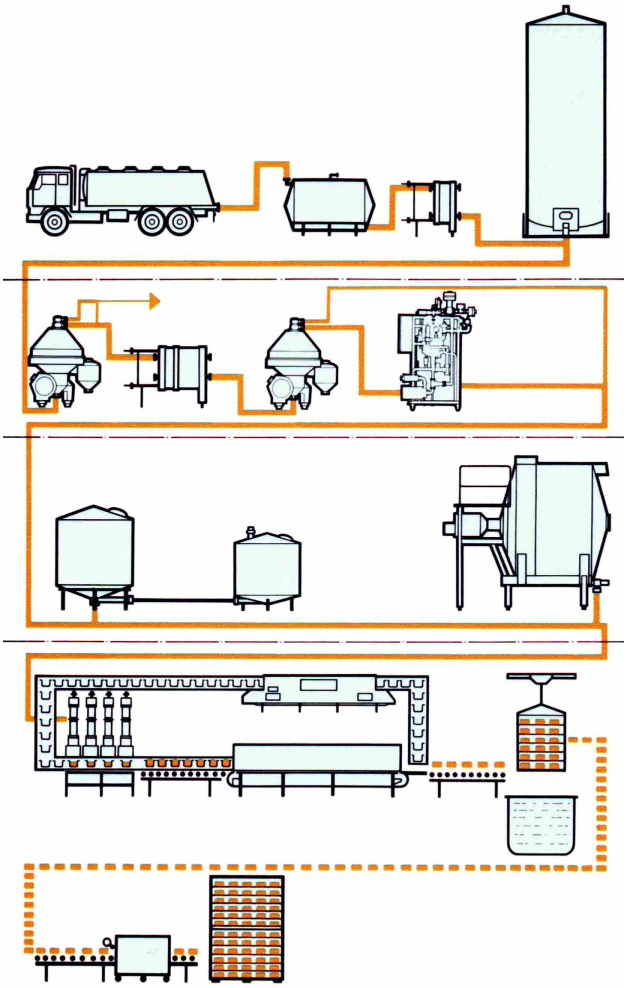


Figure 1. Simplified flowchart of cheese making

Air will be entrapped between the curd grains if the curd is moulded into cheese in the atmosphere. Carbon dioxide will then collect in these interstices and form "granular" eyes. Tilsit is an example of a granular cheese.

If the cheese is moulded below the surface of the whey, in order to exclude air, the interstices will be fewer in number, and the carbon dioxide forms round holes, eyes, when the curd is pressed. Gouda is an example of a round-eyed cheese.
A close-textured hard cheese is made with starter cultures which emit very little, or no, carbon dioxide. All the lactose is then fermented before the final forming takes place. The most well-known type of close-textured hard cheese is Cheddar cheese. This name will, in this context, be used to denote close-textured cheeses. Holes will nearly always be found in Cheddar cheese but they have a mechanical origin, caused by the processing technique.

Cheesemilk

Milk used for cheese making must be of good quality. The suitability of milk as a raw material for cheese is determined at the farm. In addition to the normal required standards of hygiene, the milk must be free from antibiotics which would destroy the starter culture. Colostrum milk and milk from diseased animals must not be delivered to cheese factories.

The most important property of cheesemilk is its ability to coagulate when mixed with rennet and the ability of the coagulum to release whey. These characteristics vary considerably in milk from cows of different breeds and even between individual animals. The differences can be evened out by mixing milk from different producers, but seasonal variations can occur. The cheese making properties' of milk can, to a certain extent, be improved by adding calcium chloride or by pre-ripening of the milk. Cold storage, mechanical treatment and intense heat treatment impair the general cheese making properties of milk.

Treatment of cheesemilk

Cheesemilk must not contain bacteria which are detrimental to cheese. Butyric-acid bacteria, for example, form spores which survive pasteurization and which may become active in the cheese and cause fermentation.
Attention must also be paid to the risk of reinfection of the pasteurized milk or cheese by undesirable bacteria which can cause discolouration and fermentation.
Treatment of the cheesemilk prior to curdmaking normally comprises clarification and possibly thermization, fat standardization, pasteurization and/or bactofuge treatment, ripening and final adjustments with various additives such as calcium chloride and colouring or discolouring agents (see also under "General milk treatment").

Clarification

It is advisable to clarify the milk efficiently prior to cheese making. The foreign matter in the unclarified milk often contains different types of micro-organisms. Most of the micro-organisms that may deteriorate the milk quality are removed with these impurities.

Pasteurization - bactofuge treatment

Pasteurization of cheesemilk is generally not compulsory, but whey used for fodder must be pasteurized. The milk for Emmenthal and Parmesan cheese must not be heated to more than 40 °C.
Cheese made from unpasteurized milk is considered to have a better flavour and aroma, but the quality of the milk is seldom so good that it is possible to take the risk of not pasteurizing it.
Pasteurization must be sufficiently intense to kill the bacteria - coli aerogenesis - which interfere with the coagulation process. Ordinary HTST pasteurization is adequate for this purpose.

Certain spore-forming micro-organisms survive pasteurization and can cause serious problems during the ripening process, One examples is Clostridium tyrobutyricum, forming butyric acid. Large volumes of hydrogen gas are produced during butyric-acid fermentation. This gas will destroy the texture of the cheese completely, not to mention the fact that buturic acid is unsavoury. More intense heat treatment would reduce that particular risk but would, at the same time, seriously impair the general cheese making properties of the milk. Treatment in a Bactotherm plant (see under "General milk treatment") makes it possible to remove as much as 90% of the bacteria in milk. This treatment is particularly effective with regard to spores, which have a higher density than bacteria. The very powerful centrifugal force generated in the bactofuge also causes some separation of protein, but this can be recovered if the bacteria concenrate (bactofugate) is sterilized and then remixed with the cheesemilk.

Standardization

Each type of cheese is often classified according to the "fat-in-total-solid" content. Therefore the fat content of the cheesemilk must be adjusted to the required fat content of the cheese. It must always have a given relationship to the casein content of the whole milk. For this reason the composition of the raw milk, regarding the casein and fat content, should be measured throughout the year and the ratio between the fat and the casein content standardized to the required value
Standardization can be accomplished either by in-line remixing after the separator or by mixing whole milk and skimmilk in tanks (see under standardization in "General milk treatment").

Pre-ripening of cheesemilk

The term pre-ripening covers two functions:

- Inoculation of starter into raw or pasteurized milk, which will then be kept for several hours at a low temperature before being processed. This improves the cheese making properties.
- Inoculation of starter into cheesemilk prior to processing in order to safeguard maturing of the cheese. When stored at a low temperature for long periods of time, 8-24 hours or more, the milk will lose some of its cheese making properties. The rennet coagulation time will increase. The real reason for this is not known but it is considered to be a result of the free or protein-bound calcium being tide in colloidal form at the same time as hydronium ions are bound. The result is a slight increase in pH. Addition of small amounts of a lactic starter will keep the pH value constant or will decrease the pH a bit (cca. 0.1 pH or 0.2-0.5°SH) during a limited storage at a low temperature (<10 °C). It is important to control the condition carefully at intervals after the inoculation of the milk. The bacterial growth will naturally stop after the subsequent pasteurization and the cheesemilk must then be inoculated with starter before renneting. The starter is added at an early stage in the process in order to safeguard the development of starter. The time from the addition of the starter to the addition of rennet is called the pre-ripening time.

- The pre-ripening with starter also can be used at higher temperature (at rennet inoculating temperature) 1-2 hours before rennet inoculating. The continuously pH control is advisable in this pre-ripening version.

The type as well as the amount of starter to be added to the cheesemilk must be determined experimentally according to circumstances. Allowance must be made for the condition of the cheesemilk, the length of the pre-ripening time, how acid the cheese is supposed to be, the required moisture content, etc. Important to know, that pre-ripening starters differ from cheese starters which develop the texture and sensory properties of cheeses. Cheese starters are always be need to use in industrial environment!

Additives in cheesemilk

The clotting ability of milk sometimes is decreased mainly due to the heat treatment. Therefore additives are often used for improving of clotting ability. This process usually called as cheese milk improving or milk conditioning.

Calcium chloride

If the cheesemilk is of poor quality for cheese making the coagulum will be soft. This result in great losses of fines (casein) and fat as well as poor syneresis during cheese making.

5 - 20 grams of calcium chloride per 100 kg cheesemilk is normally enough to improve the cheese making quality. Excessive addition of calcium chloride may make the coagulum so hard that it is difficult to cut.

When producing cheese with a low fat content, disodium phosphate, usually 10 - 20 g/kg, can sometimes be added to the milk before the calcium chloride is added.

Saltpetre
Fermentation problems may, as previously mentioned, be experienced if the cheesemilk contains butyric-acid bacteria and/or coli aerogenesis bacteria. Saltpetre (sodium or potassium nitrate) can be used to counteract these bacteria, but the dosage must be accurately determined with reference to the composition of the milk, the process for the type of cheese, etc., as too much saltpetre will also inhibit the growth of the starter. Overdosage of saltpetre may affect the ripening of the cheese or even stop the ripening process. Saltpetre in normal doses may discolour the cheese, causing reddish streaks and an impure taste. The maximum permitted dosage is about 20 grams of saltpetre per 100 kg of milk. If the cheesemilk is treated in a bactofuge plant the saltpetre requirement can be radically reduced or even eliminated. This is an important advantage as an increasing number of countries are prohibiting the use of saltpetre.

Colouring agents
The colour of cheese is to a great extent determined by the colour of the milk fat, and undergoes seasonal variations. Colours such as carotine and orleana are used to correct these seasonal variations in countries where colouring is permitted. Bleaching agents are also used, for example for blue-veined cheese, in order to obtain a "pale" colour as a contrast to the blue mould.

Cheese-ripening enzymes
In order to shorten the maturing period of certain cheese types, micro-encapsulated ripening enzymes can be added to the cheesemilk after pasteurization but before the cheese making commences. This technique is not yet fully developed and is therefore not commonly used.

Curdmaking

The curdmaking process includes a number of stages:

- Renneting
- Coagulum cutting
- Pre-stirring
- Whey drainage
- Heating
- Post-stirring

The main task of the cheesemaker during the curdmaking process is to ensure that a specific sequence of operations, known to give good results, is reproduced as accurately as possible.
The entire process takes place in a cheese making tank or vat. In modern mechanized plants the coagulum is cut and stirred with dual-purpose tools. The curd is heated by addition of hot water or by circulation of a heating medium through the jacket of the tank or vat. The whey is drained by means of strainers which follow the level of the whey during drainage. This reduces the risk of strainer blockage. The process is usually controlled from a panel. In the following description the successive stages of the process are illustrated as taking place in a traditional cheese vat with separate stirring and cutting tools.

Renneting

Coagulation of milk is the fundamental process in cheese making. It is usually accomplished by the addition of rennet. Other proteolytic enzymes may be used. The casein can also be acidified to its isoelectric point of 4.6 - 4.7.
The active principle in rennet is the enzyme rennin. Coagulation is believed to take place in two stages (Fig. 2):

- Conversion of casein to paracasein by the rennin
- Precipitation of paracasein in the presence of calcium ions

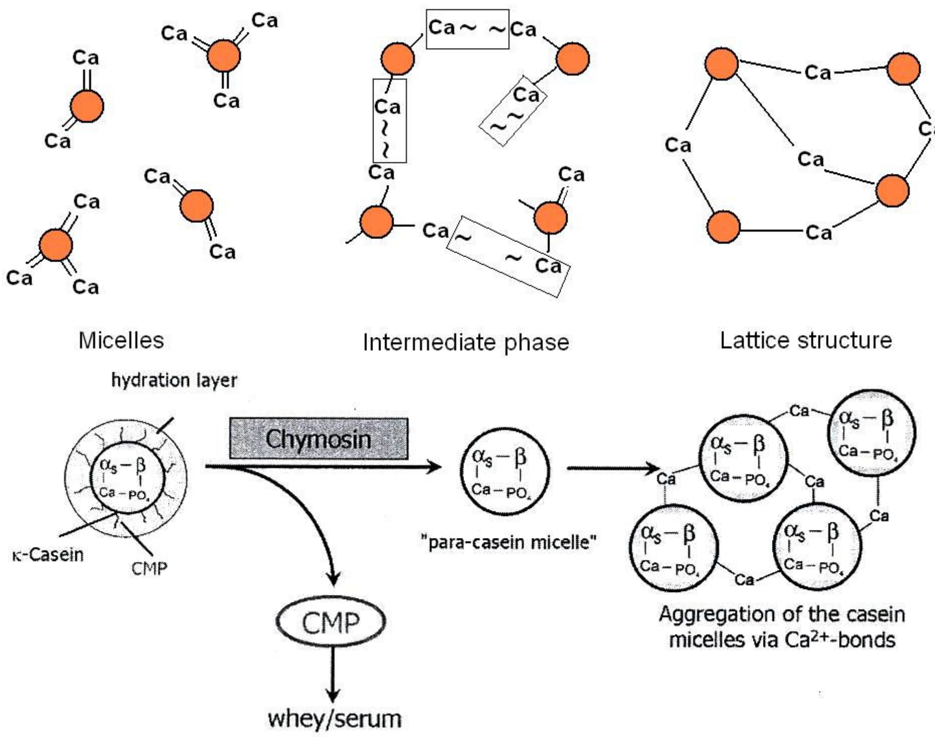


Figure 2. The coagulation process of milk

The rennin decomposes (hydrolyses) the K-casein complex into a water-soluble glucopeptide fraction and a hydrophobic para-K-casein fraction. Then the paracasein adsorbs calcium ions, which in turn link the paracasein to a network in which the aqueous phase, the whey, is enclosed.
The theory of coagulation suggests that calcium ions are essential for the formation of a coagulum. This explains why the addition of calcium chloride improves the coagulation properties of the milk. The coagulation process is governed by the temperature, acidity, calcium ion concentration and other parameters. The optimum temperature for rennet is about 40 °C, though lower temperatures, 30 - 32 °C, are always used in practice. This is partly to allow the use of a larger dosage of rennet, which assists the ripening of the cheese and helps to prevent the coagulum from being too hard. It also partly stimulates growth of the bacteria mixed into the cheesemilk.

Rennet is extracted from the stomachs of calves and is sold in liquid and powder forms. The usual strength of liquid rennet varies between 1:10000 and 1:15000, i.e. one part of rennet can coagulate 10000 - 15 000 parts of milk in 40 minutes at about 35 °C.
Due to the shortage of calf rennet, substitutes are used either separately or in various combinations with calf rennet (50:50, 30:70, etc). Commonly used substitutes are bovine rennet (from grown-up calves or heifers) and porcine (pepsin from pig rennet).

Cutting

Curd is usually cut in cheese vats after a predetermined, enzymatic reaction time has elapsed or when the operator judges the curd suitable for cutting based on a subjective evaluation of textural and visual properties of the curd. Cutting the curd after a predetermined time is questionable because there are many-many factors (such properties of raw milk, heat treating, enzyme concentration, Ca^{++}

concentration, clotting temperature, etc. which affect the coagulation (coagulation time, and curd firmness) of milk. Mainly the curd firmness could cause a variation in the optimum cutting time. But the optimum time of cutting is related to the working of curd, curd loss in whey, cheese yield, composition and quality of cheese, and at the end, fundamentally, to the economical cheese making.

Cutting the curd based on the subjective judgement of the operator can be accurate and acceptable if the observation and evaluation of milk gel is done properly (Hori, 1985).

But, if the gel is too firm at cutting time, syneresis will be retarded, resulting high moisture and acidity in cheese. If the curd is cut too soft then cheese yield will be decreased as a result of increased loss of fat and curd fines in the whey (Hori, 1985; Payne, Hicks, & Shen, 1993). Therefore the optimal cutting time determination is extremely important. Nowadays the dairy machinery producers often offer cheese vats with built-in cutting time predicting system. But these cheese vats are very expensive.

The coagulum is carefully cut into small pieces with tools equipped with knife blades or wires when it has reached the required degree of firmness.

The finer the cuts, the larger the total surface of the curd becomes and therefore more whey can be released. The design of the cutting tools is shown in Fig. 3.

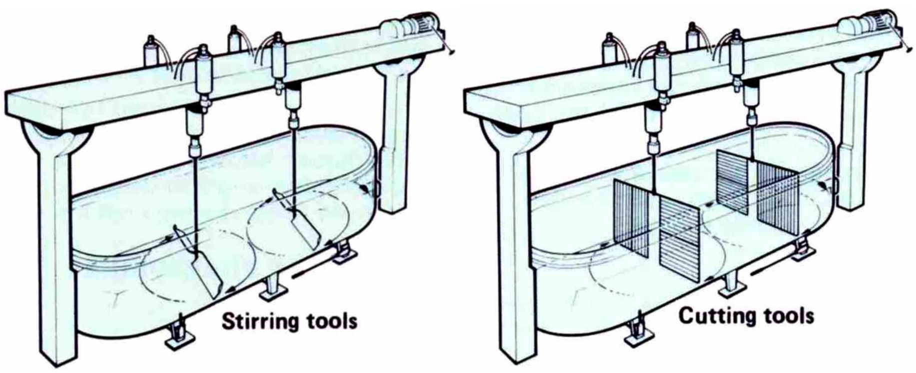


Figure 3. Conventional opened cheese vat with tools

Cutting is terminated as soon as the pieces of coagulum are of the correct size. For cheese with low moisture content, where extra high temperatures are used in the process, it is customary to cut the curd relatively fine. The curd can be cut coarser for other types of cheese which require higher moisture content. The grain size also has some effect on the texture, especially in granular cheese.

Pre-stirring

The curd grains are very sensitive to mechanical treatment immediately after cutting. The stirring must therefore be gentle. It must, however, be fast enough to keep the grains, suspended in the whey. Settling of curd on the bottom of the tank will result in lumps being formed. The lumps may affect the texture of the cheese and also cause casein losses in the whey, see Fig. 4.

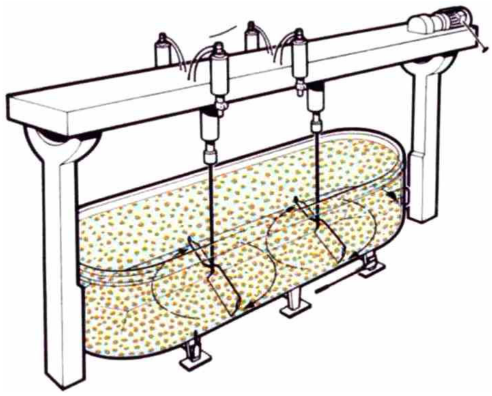


Figure 4. Pre-stirring of the curd-whey mixture

If the curd is allowed to settle, for example during whey drainage, it must be possible to stir the curd to break up any lumps that may have formed. This causes strain on the stirring mechanism, which must therefore be very strong.

The mechanical treatment of the curd and the continued production of lactic acid by the bacteria favour the expulsion of whey from the grains. In some types of cheese, such as Emmental, it is desirable to rid the grains of relatively large quantities of whey, while other types, such as Camembert, should retain much of the whey in the curd. In the latter case stirring only takes place for a short period of time after cutting.

Today cutting and stirring are often carried out with the same dual-purpose tools and there is no clearly defined boundary between these two operations.

First whey drainage

In the production of a range of cheese types considerable quantities of whey are released from the curd grains during cutting and pre-stirring, especially in the initial stages. During the actual cheese making process in the vat, heating is mainly used for further syneresis. In order to reduce the energy consumption the whey may be drained prior to heating. Thereby the mechanical pressure on the curd will increase during stirring, which contributes to a faster syneresis. For each individual type of cheese it is important that the same amount of whey - normally 35%, sometimes as much as 50% of the volume of milk - is drained off every time. This ensures uniform treatment of the curd in the vat. Whey drainage is shown in Fig. 5.

Figure 5. The drainage of whey from a traditional cheese vat by a perforated cylinder

Whey can be drained off without the stirring tools being stopped. Stationary or rotating strainers are used for this purpose. The whey is drawn off by a siphon or pump. If the stirring tools are stopped, which is the most common practice, the whey must be drained off very quickly before the curd becomes lumpy.

Warming (Heating)

Warming or cooking the curd accelerates the release of whey, but it must be gentle at first in order to avoid contraction of the grain surfaces, which would hinder syneresis. Warming will also regulate the amount of acid-producing bacteria. The warming must be accompanied by stirring in order to obtain even distribution of the heat and, at the same time, prevent curd grains from settling at the bottom of the vat and becoming squashed.

Depending on the type of cheese, warming can be carried out in the following ways:

- By means of steam in the tank jacket
- By means of steam in the jacket in combination with addition of hot water to the curd/whey mixture
- By means of hot water addition to the curd/whey mixture

The time/temperature program for warming is determined by the heating method and the type of cheese. The warming temperature usually does not exceed 38-40°C in the traditional European soft and semi hard cheese making (e.g. Trappist, Gouda). But sometimes the curd needs higher heating temperature.
Heating (cooking) to temperatures above 40°C takes place in two stages. At 37 – 38°C the activity of the lactic-acid bacteria is greatly inhibited and heating is interrupted in order to check the acidity. Then heating continues to the required final temperature. From 44°C and upwards the lactic-acid bacteria are completely inactivated. They are killed if they are kept at a temperature of 52°C for 10 to 20 minutes.
Heating curd above 44 °C is called scalding. Some cheese types, such as Emmental, are scalded at temperatures as high as 50 - 56°C. Only the most heat resistant lactic-producing bacteria survive this treatment and these bacteria will then play the principal part in the ripening of the cheese.

Post-stirring

Release of whey from the curd grains is not instantaneous. The purpose of stirring after heating is to allow time for syneresis (whey leak out from curd). A state of equilibrium is then reached, and very

little water is released during the long final phase of post-stirring.
The importance of post-stirring in the process is not limited to the effect on the moisture content and pH of the curd. Extremely long stirring times are used in the manufacture of certain special types of cheese to give them their specific aroma.

The firmness of the curd is largely determined by the post-stirring process. Firmness is an important consideration in the moulding of the cheese. A firm curd is easy to pump without losses in the form of cheese fines. On the other hand dry curd is not so easy to press by its own weight - it is difficult to obtain a good surface on the cheese. There are a number of factors in the selection of the cheese making technique which must be very exactly determined in order to ensure that the cheese has the required characteristics. Temperatures in the vat, time, whey drainage, dilution with water, addition of common salt or sodium nitrate to the whey etc. have significant effect on the final result.

Handling of the curd

The handling of the curd will differ depending on the type of cheese. When producing a round-eyed cheese the curd is normally pre-pressed below the whey surface before being finally shaped and subjected to final pressing. The grains adhere (stick) with greater force in this case. Most of the whey is discharged before moulding and final pressing when cheese with granular texture is produced. For cheese with a closed texture the curd is kept for a certain time to allow it to reach the required acidity and structure (cheddaring) before moulding and final pressing, see below.


Round-eyed cheese

If the curd is pressed below the surface of the whey, so that air cannot penetrate between the individual grains, the grains will fuse and the texture of the newly made cheese will be almost entirely closed, with only a few small air bubbles or mechanical holes which are invisible to the naked eye. The gas emitted during ripening will collect in these interstices and form the characteristic round eyes. This takes place when the lactose and the citric acid are fermented by the starter-culture bacteria or when

the Ca-lactate is fermented by specially added propionic-acid bacteria.
Part of the whey is drained off at the end of the curdmaking and filled into a prepressing vat before the cheese vat is emptied into the same pre-pressing vat. Pre-pressing can also be carried out in the cheese vat which is then supplemented with special equipment. In both cases the whole batch of curd is pressed into a rectangular or square block of curd under the surface of the whey in the vat. The pre-pressing pressure is normally 0.02 bar. The curd block is then cut into pieces of suitable size which are placed in moulds for final pressing.
Very large cheeses such as Emmenthal and Gruyere can be made in individual moulds in which they are also pressed.

The curd must not be allowed to pick up air during transfer from the cheese vat to the pre-pressing vat. The curd must be uniformly distributed in the vat before specially designed pressure plates descend to press the curd grains into a solid curd block (see Fig. 6). The bottom and sides of the vat and the pressure plates are perforated to allow the whey to escape. Pressure and pressing time must be selected in order to give good adhesion between the curd grains so that the block can be cut and the pieces transferred to cheese moulds without air penetrating between the grains.

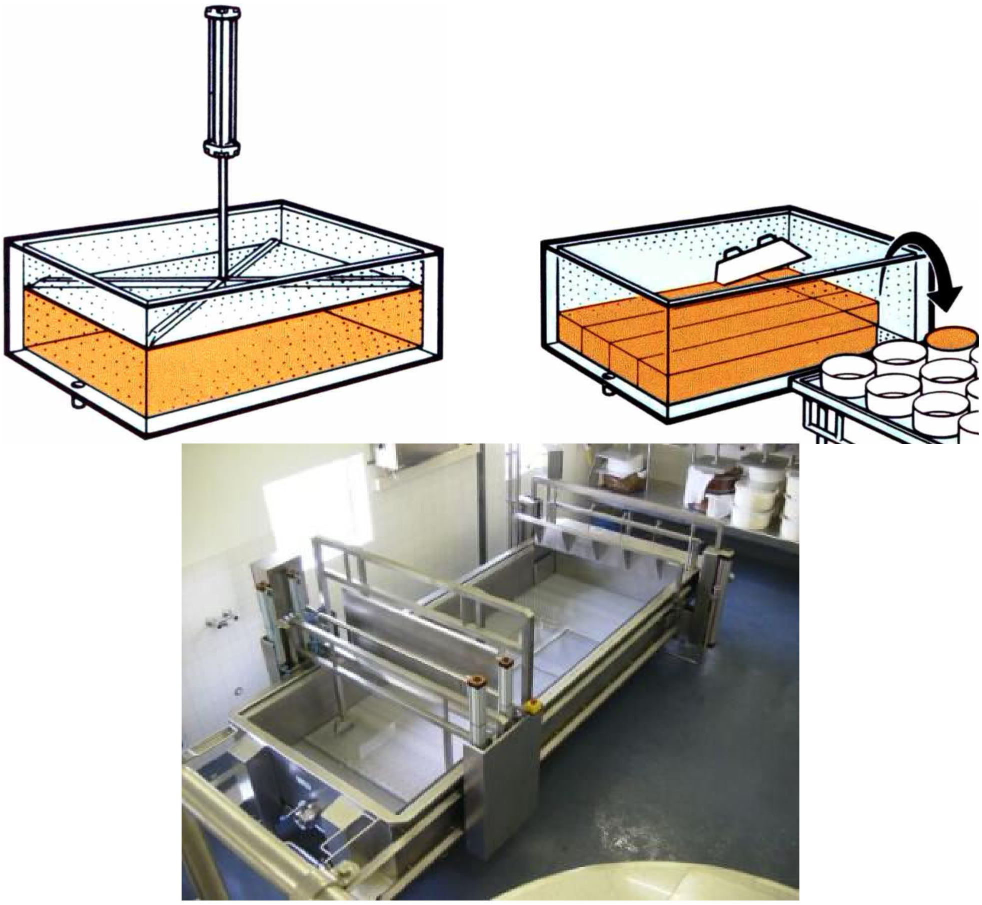
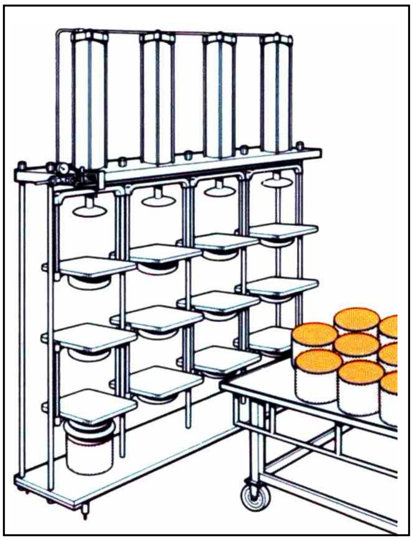


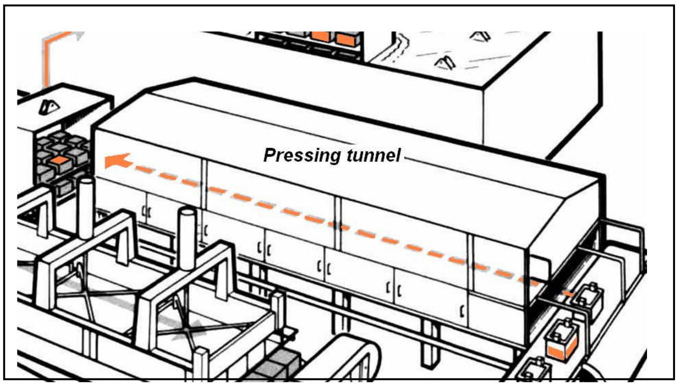
Figure 6. Principal of prepressing and Tebel type pre-pressing vat

After being pressed, the curd is marked into squares of equal size. The pieces are cut with a knife or special cutter (see Fig.6). Some press vats are fitted with mechanical devices which cut the curd into pieces of equal size.
The pieces must be slightly smaller than the moulds. If the mould is square the cheese should fit as closely as possible. In round moulds, the cheese block must sometimes be carefully compressed at the corners in order to fit in the mould. Air must not be allowed to penetrate into the cheese. The filled

mould proceeds to the final pressing (see Fig.7).



Vertical cheese press



Cheese pressing tunnel

Figure 7. Instruments for final cheese pressing

A more mechanized system for the production of round-eyed cheese is described under "Mechanized cheese making" later in this chapter.

Granular cheese

The grains will not fuse completely if the curd is moulded and pressed in such a way that air is entrapped between the curd grains. Therefore the number of interstices will be greater than when pressed below the whey surface. The gas developed by the micro-organisms will be distributed among a large number of interstices, the gas pressure in each hole will be small, and a large number of irregular eyes will be formed. The cheese will acquire a granular texture.

In order to achieve the granular texture the whey must be removed from the curd grains before moulding. This begins in the cheese vat, where a larger proportion of the whey is drained off through the whey strainer. Enough whey must be left to keep the curd grains in suspension with the help of the stirring tools. The mixture of curd and whey is then pumped from the cheese vat to moulding - either directly to perforated moulds, from which surplus whey can drain - or, which is more common, to special whey separation equipment. This can consist of a rotary strainer.

The mixture of curd and whey is pumped to the rotary strainer and distributed through a distributor in the inner part of a perforated, revolving cone. The whey flows through the perforations in the cone, is collected at the bottom of the housing and drained through a tunnel. The curd leaves the cone through the open end of the strainer and falls down an adjustable chute of stainless steel.

Moulding can also take place in a pre-pressing vat in the same way as for round-eyed cheese, but the whey is first removed in, for example, a rotary whey strainer. The curd grains are uniformly distributed in the press vat. It is then pre-pressed into a curd block which is cut into pieces of suitable size. These are transferred to moulds for final pressing.

Several modern systems are now available for mechanized whey drainage and moulding. One system is described under "Mechanized cheese making" later in this chapter.

Close-textured cheese (Cheddar)

Cheddar cheese is manufactured on a large scale in English-speaking countries, and the manufacturing process has been extensively mechanized. The close texture is obtained by subjecting the curd to treatment which causes all the lactose to ferment before moulding. A lactic culture, which forms acid rapidly, but no or only small amounts of carbon dioxide, is used. The following description refers to the traditional production method, which is also shown in Fig. 8.

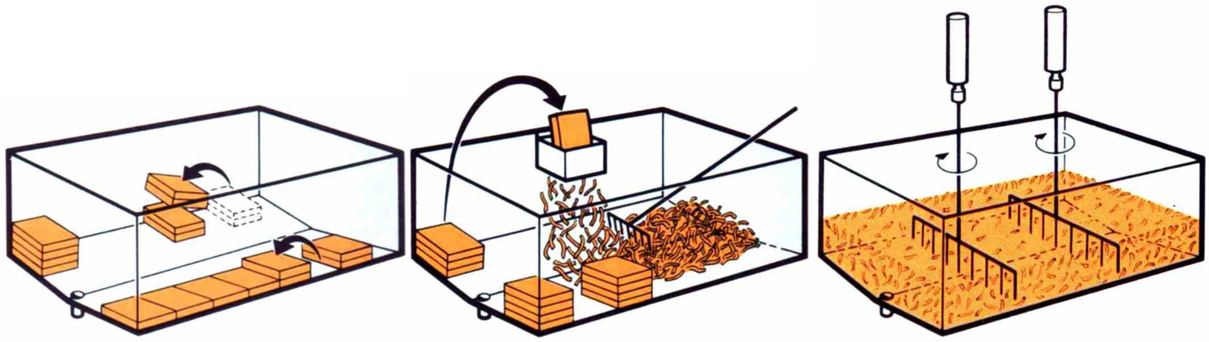


Figure 8. Traditional steps of Moulding-Prepressing of cheddar cheese

These show the individual steps more clearly. In practice the process is fully mechanized, see "Process lines for Cheddar cheese".

The cheddaring process is started when the maximum cooking temperature has been reached and the curd condition is suitable for pitching. The term "cheddaring" covers the period between the draining of the whey and milling. During this period the curd is converted into large blocks with a fibrous texture according to the following description. The curd is allowed to rest for about 15 minutes when the whey has been drained. Then the curd is cut into pieces or blocks which are placed on top of each other in pairs.

The blocks are turned and stacked three high after about 20 minutes. The top and bottom blocks change place. The turning and stacking process is repeated at intervals of about 15 minutes and the height of the stacks is increased by one layer each time. Acid develops in the curd during this procedure. All the lactose should have been fermented by the end of the cheddaring process. The whey should then have an acidity of 23 - 27 °SH (or 0.5 - 0.6% lactic acid).

The finished curd should be dense and fibrous. After the cheddaring process the blocks are milled into small pieces. "chips", in a chip mill (see Fig. 8). The chips are then salted, and the salt is well dispersed by means of stirring. Finally the salted curd is transferred to moulds. The moulded cheese continues to the final pressing.

Pressing

Pressing gives the cheese its finished shape, a firm surface and correct final moisture content. The cheese can be pressed for a longer or shorter time in horizontal or vertical presses. Pressing parameters such as pressure, time, pH and temperature must be kept at constant, specified values to ensure a correct end result.

Gravity pressing is mainly used for cheese with a high moisture content, i.e. soft cheese, but can also be used for hard cheese. In the latter case pressing takes place at a high temperature, 36 - 40 °C. Great care must be taken during this treatment to ensure that acid development is not arrested.

Short-time pressing, for two or three hours, takes place in pneumatic or hydraulic presses at 40 - 50

kPa (0.4 - 0.5 bar). The cheese is then removed from the moulds and cooled quickly. This method is used for cheese with a medium moisture content.
A longer period at a higher pressure is used for Cheddar, up to 24 hours at 100 -150 kPa (1 -1.5 bar). Other hard cheeses with low moisture content are pressed at 40 - 50 kPa (0.4 - 0.5 bar) for 24 - 48 hours. Some cheese press is shown for final pressing of cheese, see Fig 9. The main types are: individual press, vertical line press, horizontal line press, pressing tunnel.
Regardless of the pressing method, the moulds must be perforated to allow drainage of the whey which is pressed out from the cheese.

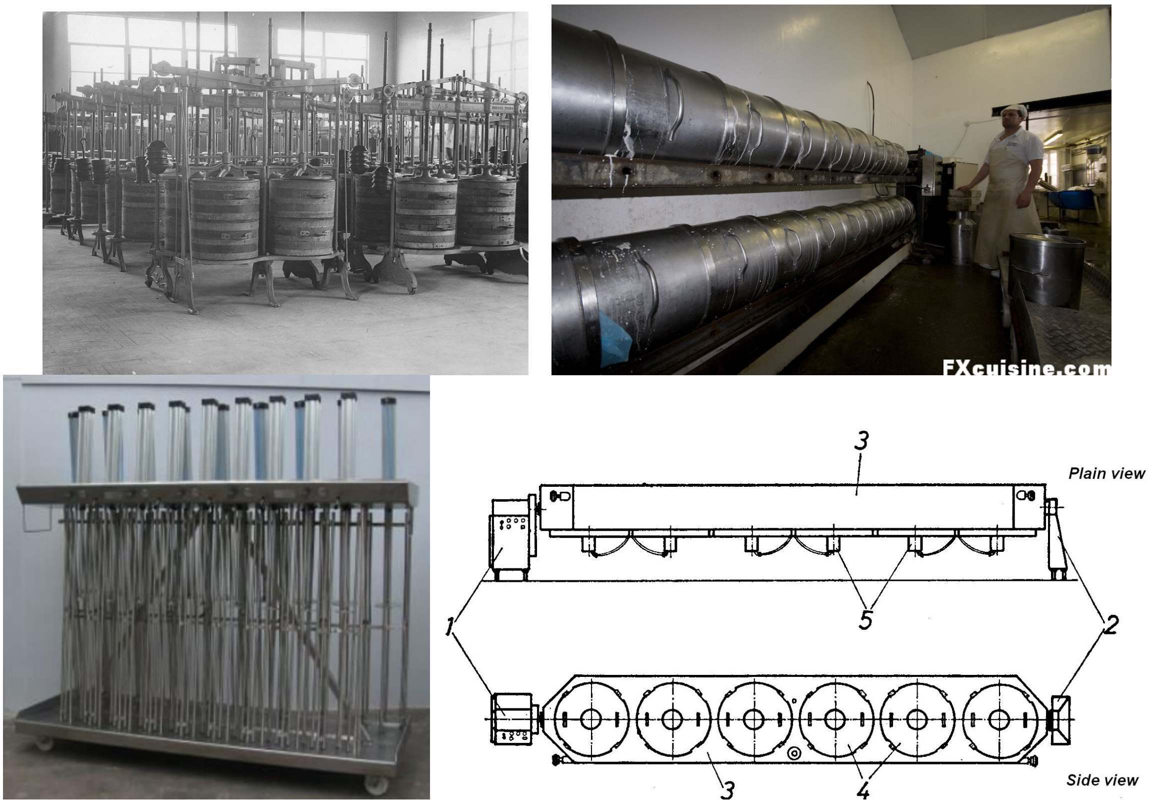


Figure 9. Some type of cheese presses

Salting

Common salt (sodium chloride, NaCl) is added for several reasons: to affect the flavour of the cheese, the starter development and thereby many of the characteristics of the cheese, moisture content and consistency of the cheese and also to improve the keeping quality.

The salt tolerance of micro-organisms varies considerably from one species to another. The activity of lactic-acid producing bacteria is, for example, noticeably retarded at salt concentrations above 0.5% if the salt is added at an early stage of the cheese making process. Salt can therefore be used to influence the acid development in the cheese and thereby most of its characteristics.
Salt is an important seasoning in foods which, like cheese, are rich in protein. The amount of salt must be adjusted to the degree of ripening in order to maintain a balance between salt and cheese aroma. Mild cheese is therefore usually less salted than strong cheese.
Butyric-acid producing bacteria are affected when the salt content reaches about 2%. Butyric-acid fermentation can to some extent be prevented by salting. Bacteria tolerating salt concentrations as high as 5% are used to produce the characteristic aroma in the manufacture of red-smear cheese

such as Tilsit. Other aroma-producing bacteria that generate the gas for eye-formation in cheese are very sensitive to salt. Salt is consequently an excellent agent for regulation of correct gas development in cheese.
Paracasein dissolves best when the salt concentration is about 5%. The best consistency is obtained when the salt content of the moisture in the cheese is at about that figure.

Methods of salting

Salt is added for *four purposes:*

- *to influence the flavour of the cheese*
- *to influence the starter development, and thereby many of the characteristics of cheese*
- *to influence the consistency of cheese*
- *top improve the keeping quality*

Salt can be supplied to cheese in four ways:

- *In the whey*   *Early salting*
- *In the curd*
- *On the surface (Dry salting)*   *Late salting*
- *In the brine*

Salt can be added to cheese in four ways: in the whey, in the curd, on the rind (dry salting) and in brine.
The first two methods are called early salting and the last two late salting. In early salting the salt is supplied before the lactic-acid fermentation is completed. This affects the acid development. A combination of early and late salting is often used, for example salting in the whey and in brine. The late salting methods usually result formation of a rind on the cheese surface.

Salting in the whey

Salt is added to the remaining curd after the first whey drainage. It is mixed in during at least 10 minutes' post-stirring. This method of salting, results in a cheese with a higher moisture content and softer consistency. It is used for both round-eyed and granular cheeses. One of the disadvantages is that the whey will contain salt. This constitutes a problem in the subsequent treatment of the whey.

Salting in the curd

In this case the salt is added when the whey has been separated. It is thoroughly mixed with the curd. This is the method used in the manufacture of Cheddar and similar types of cheese. Spices or other flavouring agents also can be mixed at this stage in to the curd. Salting the curd immediately after whey separation in rotary or vibration strainers in the manufacture of granular cheese is more difficult, as the salt is damp and it is difficult to regulate the dosage satisfactorily.

Rind salting

If dry salt is spread over the surface of the cheese, the moisture in the cheese will dissolve the salt and carry it into the interior. For this method the atmospheric humidity must be relatively high.
Hard cheese can be rind salted. It used to be common practice to rind salt Emmenthal to stop eye formation.
The method is labour craving and is therefore not very widely used for hard cheese. It is well suited to semi hard and soft cheese, which is why blue cheese is rind salted.

Salting in brine

For brine salting the cheese is placed in containers and lowered into a tank with brine at a concentration of 16 - 23% NaCl. During immersion the cheese absorbs salt and **simultaneously releases water**. The salting time depends very much on brine concentration and temperature, on size or weight of the cheese and, of course, on the required salt content of the cheese. Other substances, such as lactic acid and saltpetre, are also exchanged between brine and cheese during this period.
A number of precautions, such as heating of the brine and the use of certain additives, are taken in order to eliminate the risk of bacteria growth and the development of moulds and yeasts.

Figure 10. Early salting and salting in brine

Storage of cheese

The manufacturing process gives the fresh cheese certain characteristics which are carefully checked to establish the results of the treatment. The two most important parameters are the results of acidification (pH, remaining unfermented lactose) and moisture content. Both vary according to the type of cheese. The pH of hard cheese is 5.2 - 5.4, and that of soft cheese 4.8 - 5.1. In most cheese acidification is stopped when the correct pH has been reached, whereas the fermentation of Camembert and Brie does not stop until the pH has dropped so low that it inhibits the acid-producing bacteria. The cheese therefore contains lactose when the lowest pH value has been reached. This also applies to acid-coagulated cheese such as Quarg.

Some types of cheese, including acid-coagulated cheese (Quarg and Cottage cheese), are ready for consumption as soon as they are packed. Other types are stored for a short time to develop certain break-down of the protein, taste and aroma, principally to achieve uniform distribution of salt. Yet other types are stored for periods of varying length in order to give the cheese a definite smell, taste and consistency, to develop the correct texture, and to undergo special treatment to form a rind that will protect the cheese during storage and transportation.

The storage conditions and the storage systems must be adapted to the cheese produced. Certain types can be stored in so called green-cheese stores, where the bacteria are permitted to develop during a certain period of time before the cheese is transferred to the final ripening or maturing storage. Temperatures and relative humidities of the stores are in most cases carefully controlled and are adapted to the type of cheese.

Cheese in the green-cheese store is turned daily to allow the surface to dry and to give a symmetrical shape as the cheese will subside under its own weight. Treatment with mould-inhibiting agents, if permitted, plastic coating and/or waxing of the rind take place at an early stage of the storage period and are adapted to the type of cheese to be produced.

In the warm store toe cheese is kept at a higher temperature in order to encourage the bacteria responsible for gas production, so that the eyes begin to develop. The cheese is kept here for 2 - 3 weeks. Then it is transferred to the ripening store.
The temperature in the ripening store must be adapted to the technology of the cheese in question. For certain types, e.g. Edam and Gouda, temperatures of 11 - 14 °C and relative humidities of 65 - 70% are used.
For Cheddar types the storage temperature is lower, 3 - 8 C, and the relative humidity higher, 80 - 85%.
During the ripening period the lactose, citric acid, lactates, proteins and fat are broken down. The breakdown of carbohydrates (lactose) to lactic acid is caused by the starter bacteria. Protein decomposition to peptides and amino acids is caused by a combined action of the rennin enzyme and the starter bacteria.

Finally, the breakdown of fat to glycerin and free fatty acids, and the formation of aldehydes and ketones are caused by the lipase enzyme. The number of products formed during the breakdown of the proteins is a measure of the extent of the ripening process. The cheese aroma is obtained through a fine balance of certain substances such as fatty acids, aldehydes, ketones, amino acids and peptides.
Smear-treated cheese ripens mostly from the surface inward. In this type of cheese there is an advanced breakdown of protein, caused by red smear bacteria and moulds, in some cases all the way to ammonia. The breakdown of fat to free fatty acids is important in the ripening of some types of cheese but most important in blue-veined cheese, where the fatty acids are further broken down. This gives the cheese a strong, specific aroma.

In blue-veined cheese the quantity of air in the cheese is not sufficient to stimulate growth of the blue mould. In order to increase the air content this cheese is therefore pierced with needles from one flat side through the cheese to the other side. After a certain time, when the mould growth has reached the required stage, the holes are closed mechanically.

Packing

Cheese is usually packed before it leaves the store. The packing materials vary, but their purpose is to protect the cheese from flavour contamination, external micro-organisms, insects, etc., to prevent loss of moisture, to preserve the shape of the cheese, and to enhance its appearance.
Hard cheese is usually given a protective coating of wax or some type of plastic or resin. Cheddar is normally wrapped in cheese cloth, which is then waxed.
Semi-hard and soft cheese is often wrapped in aluminium or plastic foil and packed in cardboard boxes.

Development in plastics technology has now produced plastic foils which have made it possible to manufacture rindless cheese. This cheese ripens in the plastic film, which makes storage much simplier and is labour saving.
Moisture losses through the film are low and rindless cheese is therefore made with lower original moisture content than normal. Strict demands are made on the quality of the plastic film. It must be completely impermeable to oxygen, carbon dioxide, water and water vapour. It must not contain toxic substances, must be easy to handle and cheap.
Polyvinyl and polyethylene films are some of the most commonly used wrapping materials. They are also used by cheese factories which make portion-packed cheese.

9. Mechanized cheese making

Mechanization has been extensively introduced in cheese plants in recent years; many difficult and laborious operations have now been taken over by machines. Some examples of modern process lines for a few types of cheese will be briefly described.
Fig. 11 shows modern cheese tanks that have replaced the traditional vats.
Such tanks are built for batches of up to 20 000 litres of milk. The tank has a combined cutting and stirring tool. The function of the tool is determined by its sense of rotation. I n order to facilitate the addition of rennet the tanks can be equipped with a separate sprinkler system. Heating and cooling are accomplished by circulation of the media through the jacket or by direct addition of hot water through a sprinkler system.

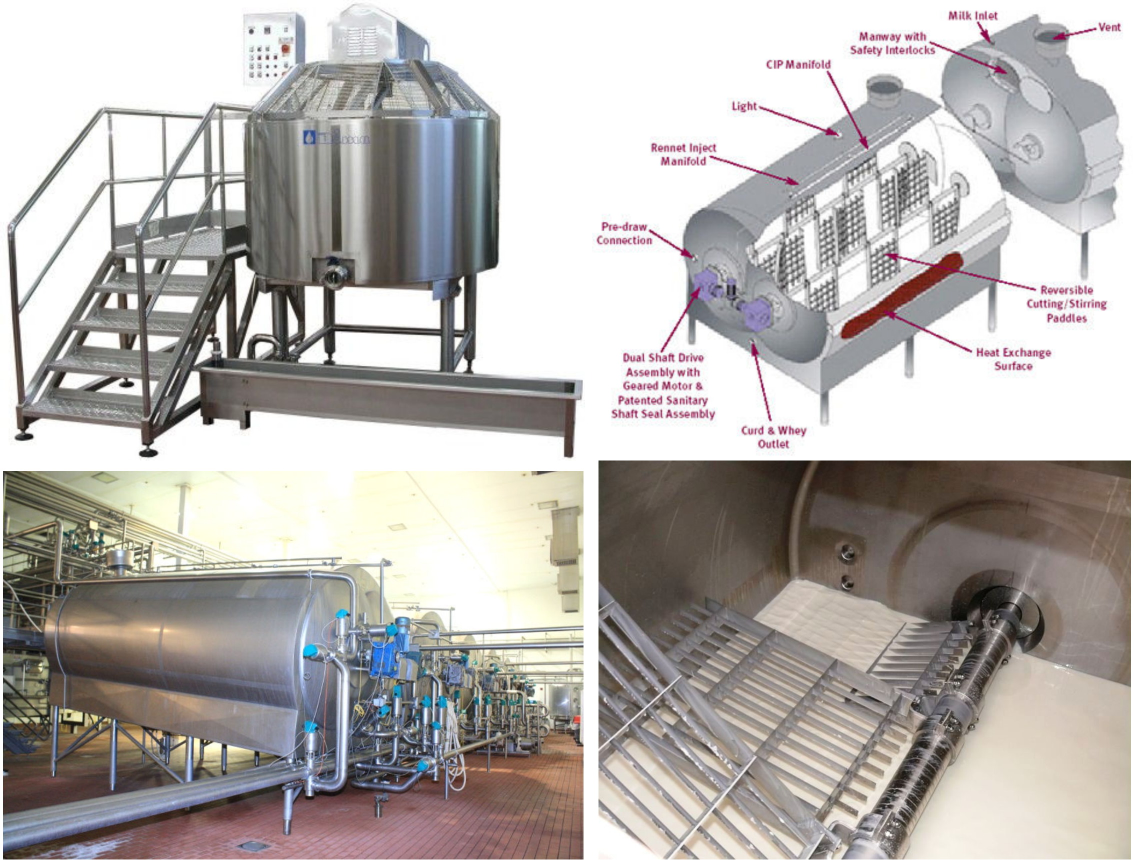


Figure 11. Modern, closed cheese tanks

Whey drainage is carried out by means of a specially designed whey strainer. The vertical position during whey drainage is controlled by electrodes so that it follows the level of the whey as drainage proceeds. The entire curdmaking process is controlled from a panel according to a preset program in which all times, temperatures and operations are specified.

Process line for round-eyed cheese

Fig. 11 shows a cheese tanks can be installed as part of a system for mechanized production of round-eyed cheese. The process line also includes a pre-pressing vat, a tunnel press, brine salting basins and conveyor systems. Mechanized cheese production line is shown in Fig 12.

The mixture of curd and whey is transferred from the cheese tank to the pre-pressing vat, which is a rectangular container with perforated conveyor plates in the bottom. When the curd has been transferred to and spread out in the vat, perforated pressure plates descend to prepress the curd below the surface of the whey. During this operation the curd grains are fused together to form a continuous block of curd with no air inclusions.

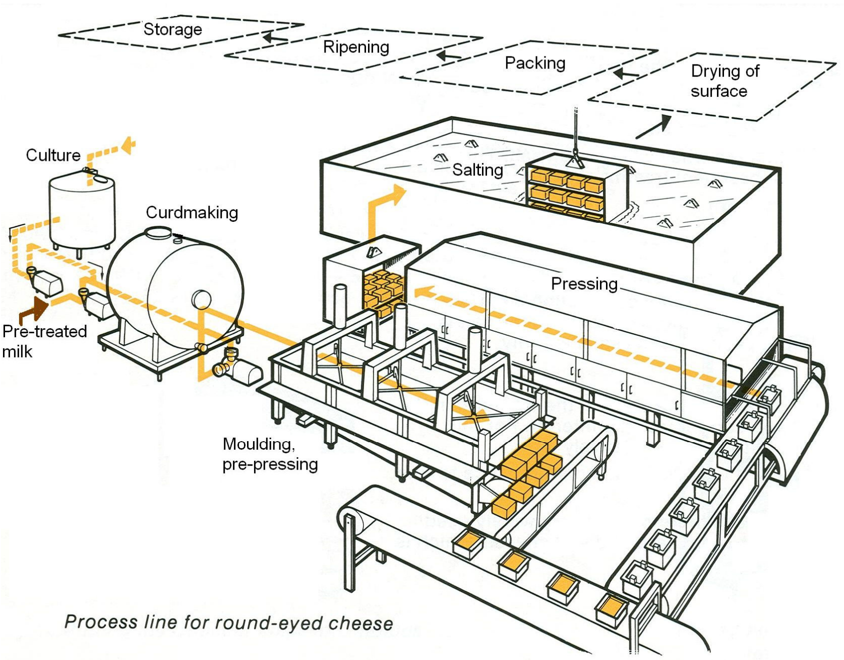


Figure 12. Round-eyed cheese process line

The pressure plates are removed at the end of the pre-pressing and the conveyor in the bottom of the vat is started. The block is discharged at the front end of the vat, where it is cut into bars of equal width by stationary vertical blades. The conveyor stops and a guillotine cuts the ends of the bars into square blocks when the correct length has been discharged. These bars are placed in moulds and covered with lids. The filled moulds continue on a conveyor to the tunnel press. This continues until the pre-pressing vat has been emptied.

A more advanced system is the continuous pre-pressing, block cutting and moulding machine as shown in Fig. 13. This machine was originally designed for the production of round-eyed cheese. The principle is as follows: The curd/whey mixture, normally in a ratio 1:4, is introduced at the top of the column, the bottom of which is closed by a movable knife. The whey drains through the curd via the perforated sections of the column. The level of the whey surface is controlled by means of top mounted level electrodes. This is very important as it prevents air from being enclosed in the curd.

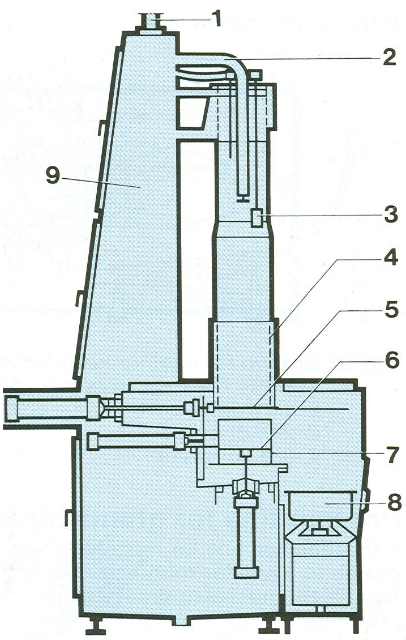


Figure 13. Continuous pre-pressing and mould-filling machine

1:roto-strainer; 2:Curd/whey inlet; 3:Curd level indicator; 4: Perforated whey discharge plate; 5: Combined bottom/knife; 6:Peforated dosing/pressing plate; 7:Sliding cylinder; 8:Cheese mould; 9:Valve and pipe cabinet

After a pre-set time, the curd at the bottom of the column has been pressed to the required firmness by its own weight. The knife at the bottom is then withdrawn and the column of curd descends. The knife moves forwards and cuts off the bottom piece. This piece is removed from the machine and placed in a mould on a conveyor belt underneath. The filled mould then proceeds to final pressing.
The final pressing takes place in a tunnel press (Fig 14) with individual press cylinders for each mould. When the press has been filled, the cylinders are lowered and pressure is applied to the lids of the moulds. Pressure and pressing time must be adjusted according to the type of cheese.

Figure14. Tunnel pres with individual press cylinders

At the end of pressing the cheeses are forced out of the cheese moulds. They are discharged from the press and loaded in containers, which are carried by a hoist to the brine basins and immersed in brine for a predetermined time. After brining, the containers are lifted out of the basin. The cheese is then transported by truck to the store for final treatment.

Process line for granular cheese

A mechanized line for manufacturing granular cheese is similar in design to a line for round-eyed cheese, except for the fact that the equipment must also separate the whey from the curd grains before pressing. Vibration or rotary strainers are often used for this purpose.

Process line for Cheddar cheese

A variety of mechanized systems has been developed for the cheddaring process. Fig. 15 shows a system for continuous production in which the curd is carried on conveyor belts to the various stages. This system can handle all functions from the point where the curd/whey mixture is pumped from the cheese tank to the delivery of milled and salted curd for pressing.
The machine is built up of four conveyors assembled above each other in a stainless steel frame. The curd/whey mixture from the cheese tank is distributed on a whey drainage screen (1) where most of the whey is discharged. The curd falls down on the first conveyor (2) which is perforated for final whey drainage. Independently driven stirrers make the whey drainage very efficient.

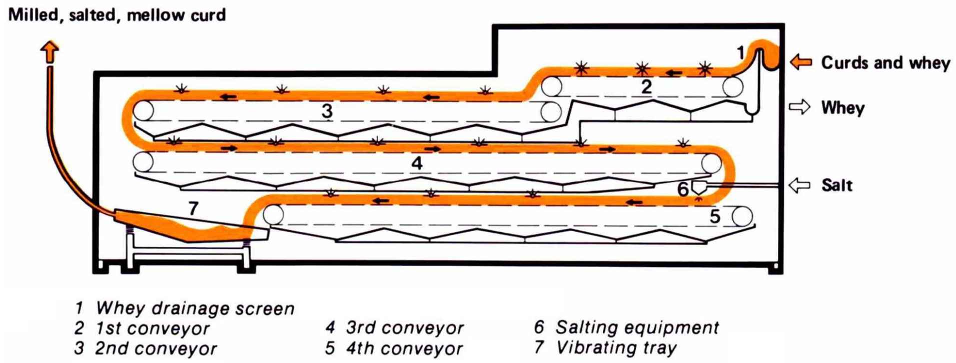


Figure 15. Continuous cheddar production system

On the second conveyor (3) the curd can mat and fuse. When transferred to the third conveyor (4) the curd bed is turned upside down and the matting and fusing processes are continued. At the end of the third conveyor the curd bed is milled to equally sized chips which then fall down on to the fourth conveyor (5).
For the production of stirred-curd Cheddar types conveyors 3 and 4 also have stirring tools. In the production of Colby cheese, which is a washed type of Cheddar, conveyor 2 also has a sprinkler pipe. When producing the stirred types of Cheddar the milling device is not in operation as the curd is not permitted to fuse.

On the last conveyor the chips (or curd grains) are sprayed (6) with brine or sprinkled with dry salt. At the same time they are stirred for efficient mixing. The chips are fed from the fourth conveyor either on to a vibrating tray (7) which keeps them separated until they are transported to the block-forming station or, alternatively, on to a conveyor for transportation to a mould filling unit.

Fig. 16 shows a modern plant for the manufacture of Cheddar cheese. The plant includes cheese tanks (1), the cheddaring machine (2), a block forming station (3) and packaging machines. From a vibrating tray the cheddared and salted curd is fed, by means of vacuum, to the block forming tower (3). The chips are pressed together by the static height, the vacuum and the resting time respectively. After a suitable period of time, for instance every 100 seconds, the column of curd is cut into blocks of 20 kg by a guillotine at the bottom. The separated block is packed into a plastic bag, weighed (4) and vacuum sealed (5). The vacuum-packed cheese then passes through a shrinking tunnel (6) in which the plastic wrapping material is shrunk to a tight-fitting skin round the cheese. This gives the cheese a dense, smooth surface and prevents the growth of mould.

In order to prevent deformation, each cheese block is placed in a strong, close-fitting carton (7) before being palletized (8) and transported to the ripening store.

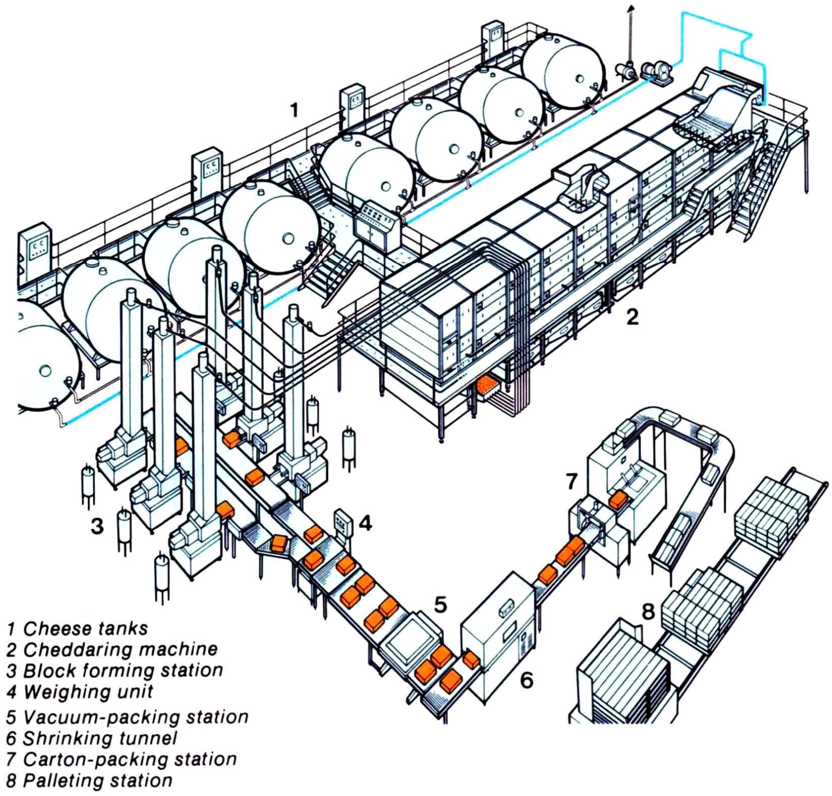


Figure 16. Modern plant for the manufacture of cheddar cheese

Block-forming systems

Pressing in moulds is still the most common method of giving Cheddar cheese the final shape. The handling of the moulds requires an extensive system of conveyors, washing machines, etc. The moulds are expensive and must be replaced at intervals due to wear. There is also the cost of pressing equipment. Altogether the final forming of the cheese is a very expensive and labour craving.process which also takes up a great deal of space.

In recent years several systems, such as the one have been developed for forming cheese without using moulds. Fig. 7 shows a cross section through a block former. The prepared curd is drawn by vacuum to the top of the tower. In the tower the curd begins to fuse under gravity and forms a continuous column. The curd column is subjected to a constant vacuum throughout its height. This results in the product at the base of the column being completely consistent, uniform and free from air.

Here, regular blocks are automatically lowered, guillotined and ejected by the pneumatically operated mechanisms for the final stages of packing, sealing and ripening. The total resting time for the curd in the block former will be approximately 30 minutes for each block.
The process is not only automatic but also continuous. As each block is ejected, the curd sensor allows the next feed of prepared curd into the cyclone. The blocks normally weigh 20 kg.

Ultrafiltration (UF) in cheese manufacture

The main process in conventional cheese manufacture is the concentration of the milk fat and proteins by means of whey separation. UF offers a possibility for concentration of the milk fat and protein without the losses encountered in conventional cheese making. The UF-concentrated product has the same dry solids content (OS) as fresh cheese.
UF can also be used for pre-concentration. Ultrafiltration is used in three different ways in cheese making.

- Pre-concentration to low concentration, using a concentration factor (CF) of 2, followed by conventional cheese making in traditional equipment.
- Concentration to moderate concentration (CF = 3 - 5) and subsequent cheese-making in a modified cheese process, including some whey drainage. The equipment differs considerably from the traditional equipment.
- Concentration to the final Total Solid content of the cheese (CF = 6 - 8) and using entirely newly designed cheese making equipment.

The first two methods can be used for the manufacture of all cheese types, whilst the third method makes it possible to manufacture completely new cheese products.
The first method is particularly suitable where extra capacity is needed in a plant. Conventional cheese vats or tanks are used. The manufacturing technique is mainly the same as for conventional cheese-making, with the exception that adjustments must be made in the amount of starter, intensity of stirring and in cooking temperature and time. The pre-concentration in the UF unit results in an increased protein content. This increases the firmness of the curd which, in turn, results in demands on reinforcement, or even a special design, of the cutting and stirring tools. The traditional cutting tools are capable of handling curd with a protein content of up to approximately 7%, which limits the concentration factor to 2.
The second method is quite interesting with regard to economical returns and manufacturing possibilities. With this method the traditional types of cheese can be manufactured from smaller quantities of milk per kg cheese, i.e. the cheese yield is bigger. The fat and protein losses with the whey are minimized with this method see Table 1. The raw material for cheese making is a standardized concentrate. New types of curd-making machines have been developed, as the traditional equipment cannot be used. The cheese tank has been replaced by a UF plant and a curdmaking machine.

Table 1. Amount of liquid removed as whey and permeate (%)

Method	Permeate	Whey
Traditional	0	100
Method 1	50	50
Method 2	80 - 90	20 -10
Method 3	100	0

The third method is still an object for research and development. The aim is to produce cheese without any losses of fat and proteins. Today this is possible with fresh cheese like Quarg and cream cheese while semihard and hard cheese require further development. Fig. 17 shows an example of cream-cheese production where the milk is concentrated by means of UF to the final concentration.

Advantages of UF in cheese making

UF for pre-concentration and the special curdmaking machines have several advantages. The cheese vats or tanks are replaced. Some cheese like Cheddar and Mozzarella may also be continuously manufactured by means of special equipment for the fusing of the curd and for the whey drainage.
The major advantages in utilizing UF in cheese making are the possibilities of continuous production

with uniform product quality and increased yield. The yield increase is due to the effective retention of the whey proteins and a reduction in the losses of fat and minerals with the whey. The whey proteins, to a certain degree, substitute the casein in the cheese.
The retention of whey proteins is determined by the concentration factor. When the milk is concentrated to the final TS content of the cheese the extra yield will be 22% based on skim milk only. Lower concentrations will result in yield increases from 5 to 15%.

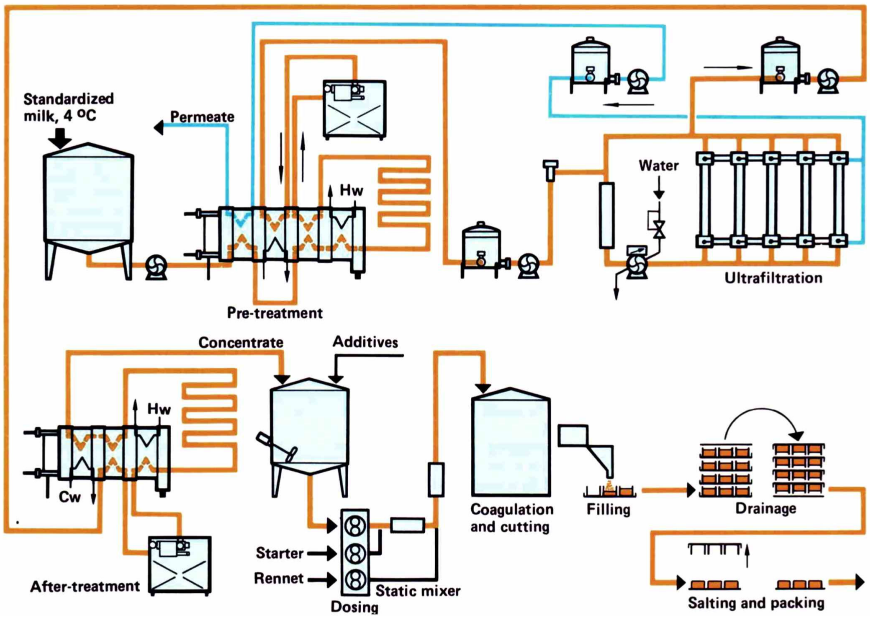


Figure 17. Production line for cream cheese

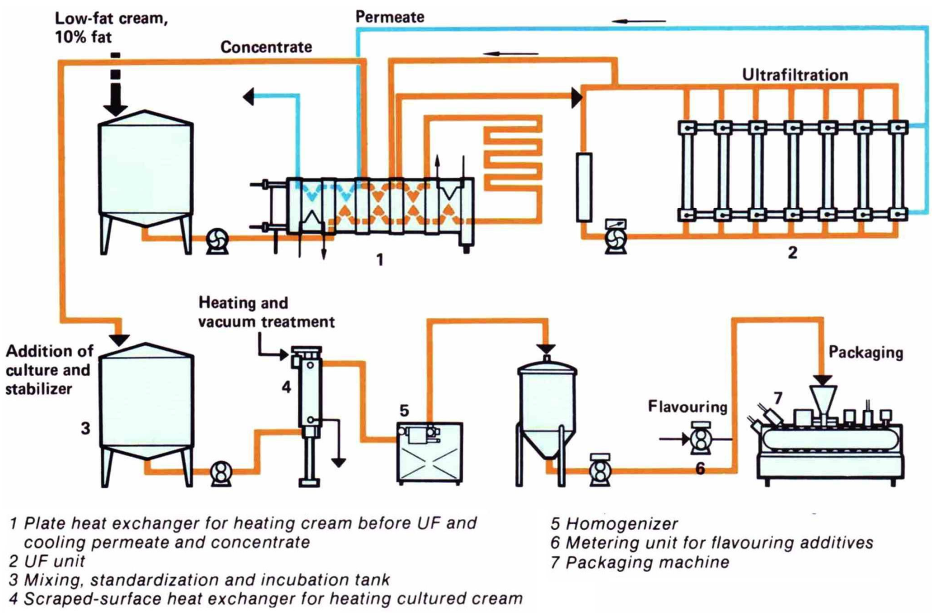


Figure 18. UF production line for Tilzit type of cheese

10. Milk powder - drying

The method of preserving various foodstuffs by drying them and thereby depriving the micro-organisms of water, necessary for their growth, has been known for centuries. According to Marco Polo's accounts of his travels in Asia, Mongolians produced milk powder by drying the milk in the sun. Today milk powder is produced on a large scale in modern plants. Skim milk powder has a maximum shelf life of about 3 years. Whole milk powder has a maximum shelf life of about 6 months. This is due to the fact that the fat in the powder oxidizes during storage, with a consequent gradual deterioration in taste.

What does drying involve?

Drying denotes that the water in a liquid product - in this case the milk - is removed, so that the product acquires a solid form. The water content of milk powder ranges between 2.5 and 5%, and no bacteria growth will occur at such a low water content. Drying extends the shelf life of the milk, simultaneously reducing the weight and the volume. This reduces the cost of transporting and storing the product. Freeze-drying has been used for producing high-quality powder. In this process the water is evaporated from the milk under vacuum. This method offers advantages from the quality aspect, as the protein fraction is not affected. The powder will always be affected to a greater or lesser extent if drying is carried out at a higher temperature. Freeze-drying has not become widely used, partly because of the high energy demand.

Commercial methods of drying are based on heat being supplied to the product. The water is then evaporated and removed as steam. The residue is the dried product - the milk powder. Two principal methods are used for drying in the dairy industry: roller drying and spray drying. In spray drying, the milk is first concentrated by evaporation and then dried in a spray tower.

During the first stage of drying, the excess water, in free form between the particles of the dry solids, is evaporated. In the final stage the water in pores and capillaries of the solid particles is also evaporated.

The first stage is relatively fast, whereas the last stage demands more energy and time. The product will be significantly affected by the heat if this drying is carried out in such a way that milk particles are in contact with the hot heat transfer surfaces - as in the case of roller drying. The powder may then contain charred particles which impair the quality.

Various types of powder

Dried milk is used for many applications, such as:

- recombination of milk
- mixing into dough in the bakery industry in order to increase the volume of the bread and to improve its water-binding capacity. The bread will then remain fresh for a longer period of time.
- mixing into dough in the confectionery trade in order to make the pastry crisper
- replacing eggs in the bakery and confectionery trades
- producing milk chocolate in the chocolate industry
- producing sausages and various types of ready-cooked meals in the food industry and institutional kitchens
- producing baby foods as a substitute for mother's milk
- production of ice-cream
- animal fodder.

Each field of application places its own specific demands on the milk powder. If the powder is to be mixed with water in recombined milk for consumption it must be easily soluble and have the correct taste and nutritive value. A certain caramellization of the lactose is beneficial for chocolate production.

In the first case gentle drying of the product in a spray tower is essential, whereas in the second case the powder must be subjected to intense heat treatment in a roller dryer. Two types of powder are therefore distinguishable - roller dried powder and spray dried powder. Table 1 shows an example of the standards applicable to skim milk powder. The solubility of spray powder is very good, whereas that of roller dried powder is appreciably poorer. The latter is due to the intense heat treatment in roller drying.

Table 1. Quality of skim milk powder

Property	Values
Fat content	max. 1.0%
Water content	max. 3.5%
Acid content in the form of milk acid	max. 0.15%
Lactose content	max. 150 mg/100 9
Added materials	none
Solubility	max. 0.5 ml
Bacteria/g	max. 50,000
Coli	0.1 g negative
Smell and taste	no off-flavours
Appearance	white or slightly yellow-no coloured particles

Depending on the intensity of the heat treatment, milk powder is classified into one of the following categories:

- Low-heat (LH) powder
- Medium-heat (MH) powder
- High-heat (HH) powder.

The quality is indirectly determined by measuring the content of non-denatured protein. The degree of denaturation can be classified according to the Whey Protein Nitrogen Index (WPNI). The following classification is used:

- LH-powder, WPNI >6.0 mg/g undenatured whey protein
- MH-powder, WPNI = 1.51 - 5.99 mg/g undenatured whey protein
- LH-powder, WPNI <1.51 mg/g undenatured whey protein

Low-heat powder is used for ali types of recombined milk products, such as cheese and baby food, medium-heat powder is used for recombined condensed milk products and high-heat powder is used in the bakery, chocolate and prepared food industries.

Instant-milk powder

Methods for the production of milk powder with extremely good solubility - known as instant powder - have been developed in recent years. This powder has a larger grain size than normal spray powder and dissolves instantly, even in cold water.

Production of milk powder

In the production of roller dried powder, the pre-treated milk is admitted into the roller dryer and drying takes place in one stage to the required dryness.

In the production of spray dried powder, evaporation first takes place under vacuum to a DS content of about 45 - 55%. Final drying takes place in a spray tower. The powder is then filled in cans, paper bags, laminated bags or plastic bags, depending on the powder quality and the requirements of the consumers.

Raw material

Very strict demands are made on the quality of the raw material for the production of milk powder. Table 1 shows that the number of bacteria per gram of powder must not exceed 50000, or even 30000 in some countries. This corresponds to about 5 000 (or 3000) bacteria per litre of reconstituted product, provided that no reinfection occurs. In view of the fact that spray powder production includes vacuum evaporation, it is as important as in the production of condensed milk to keep the heat-resistant bacteria flora under control, so that the bacteria will not multiply during evaporation. Bactofuge treatment is therefore also used in powder production in order to remove bacteria spores from the milk, thereby improving the bacteriological quality of the end product.
The milk for powder production must not be subjected to excessive, intense heat treatment prior to delivery to the milk powder plant. Such heat treatment would cause the whey protein to coagulate and the solubility, aroma and taste of the milk powder would be impaired. The milk is subjected to the peroxidase test or the whey protein test in order to determine whether the preceding heat treatment was too intense. Both of these tests indicate whether or not the milk was previously pasteurized at a high temperature.

Pre-treatment

In the production of skimmilk powder the milk is clarified in conjunction with fat separation. This is also the case if the fat content is standardized in a direct standardization system. Whole milk used for producing the powder, must first be clarified.

Pasteurization

It must take place at least to a negative phosphatase test. In the production of dried whole milk the heat treatment must be so intense that the lipases will also be inactivated. This normally involves high-temperature pasteurization to a negative peroxidase test.

Evaporation

Evaporation occurs when molecules receive enough energy to escape in the form of vapour from a solution of a solid or liquid. The rate of escape of the surface molecules depends primarily on the temperature of the liquid, the pressure above the liquid surface and the type of evaporator (rate of heat transfer to the product). Heat is taken from the surroundings as water molecules escape from the surface. The liquid will continue to evaporate until it has left an open container. In a closed container, with a space above the liquid, evaporation will continue until the air is saturated with water molecules. Removal of water from a liquid product by means of evaporation is enhanced by adding heat and by removing the saturated air above the liquid. This is carried out by forcing air over the liquid or by decreasing the pressure by creating a vacuum on the surface.

Boiling

Boiling is evaporation which occurs throughout a liquid, as a contrast to a surface phenomenon. Heat is normally applied to the bottom of a container in which a liquid is placed. The bubbles form close to the heat source and move to the surface of the liquid. When heating continues, the entire mass is heated and the vapour bubbles continue rising to the top of the liquid surface. This results in boiling. Agitation occurs as a result of the formation of bubbles at the heated surface and the movement of bubbles through the liquid. The extent of agitation depends on the heat flux. The temperature does not increase if the heat flux is increased, but the rate of evaporation is increased. During boiling the pressure of the vapour in the liquid must exceed the air pressure slightly.

Evaporators

Milk and milk products may be treated in the evaporator for removal of water in order to obtain a product such as concentrated, condensed, evaporated milk, or other milk products. Water is usually removed from liquid milk in an evaporator before drying. Milk products are normally condensed from an initial solids content of 9 to 13% to a final concentration of 40 to 50% total solids before the product is pumped to the drier.

Evaporation systems may be single-stage or multiple-stage (also called "effect") with 2, 3 or more evaporator or vacuum units. In the dairy industry the single-stage evaporator is often called a vacuum pan. In the multiple-stage evaporator the units operate at decreasing pressure as the product moves through the units.

The norm al practice for milk and other food products is to operate the evaporators at a vacuum so that the evaporation and boiling temperatures are lower than at atmospheric pressure. With lower evaporation temperatures there is less heat damage to the products.

Evaporator development began in the 1850's and has resulted in many shapes, sizes, and types of units. The major objective is to transfer heat from a heat source to the product in order to evaporate water or other volatile liquids from the product.

Circulation evaporators

Circulation evaporators can be used when a low degree of concentration is required or when small quantities of product are processed.

During yoghurt production, for example, evaporation can be utilized to concentrate the milk 1.1 to 1.25 times, or from 13% to 14.5% or 16.25% respectively. In this treatment, deaeration and the release of off-flavours take place simultaneously. The circulation evaporation process is shown in Fig. 1.

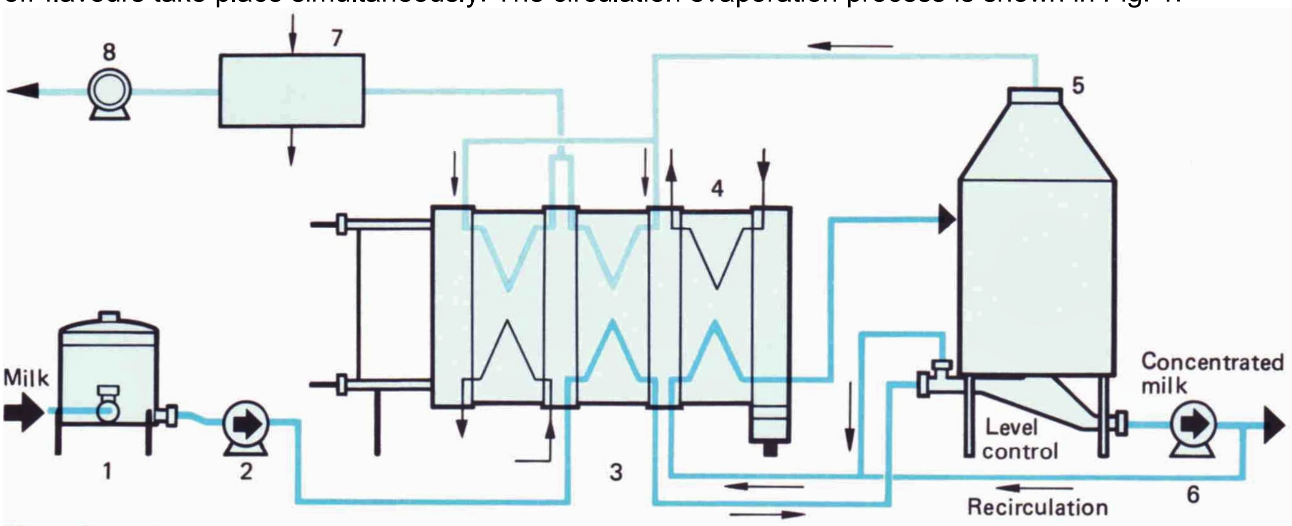


Fig. 1 Circulation evaporator
1 Balance tank,
2 Feed pump
3 Preheating section
4 Temperature adjustment section
5 Vacuum chamber
6 Recirculation pump
7 Condenser
8 Vacuum pump

Fig. 1 Circulation evaporator

The milk, heated to 90 °C, enters the vacuum chamber tangentially at a high velocity and forms a thin, rotating layer on the wall surface, see Fig. 2. During the rotation on the wall some of the water is evaporated and the vapour is condensed. Air and other gases which cannot condense are extracted by a vacuum pump via the condenser. The product eventually loses velocity and drops towards the inwardly curved bottom and is discharged through a bottom outlet. One part of the product is pumped by means of a centrifugal pump via the heat exchanger for temperature adjustment, and is then recirculated to the vacuum chamber for repeated evaporation. A large amount of product must be recirculated in order to reach the desired degree of concentration. The flow through the vacuum chamber is 4 to 5 times the inlet flow to the plant.

The falling-film evaporator

The falling-film evaporator is the type most often used in the dairy industry, see Fig. 3. The tubes are vertical and the product forms a thin film on the inside of the tubes, which are surrounded by steam. The product is preheated to a temperature slightly above the temperature of generation in the evaporator. From the preheater the product flows to the upper section of the evaporator, see Fig. 4. Creating a vacuum in the evaporator will reduce the evaporation temperature to below 100 °C. By means of a specially shaped nozzle (1), product (2) is distributed over a spreader plate (3). The product is slightly superheated and therefore expands as soon as it leaves the nozzle.

Part of the water is vaporized immediately. The steam formed forces the product outwards against the inside of the tubes and it runs down the walls of the tubes as a thin film. The water content of the film evaporates rapidly as the product passes through the tubes. A steam separator is fitted under the evaporator and separates the steam from the concentrated product, see Fig. 2.

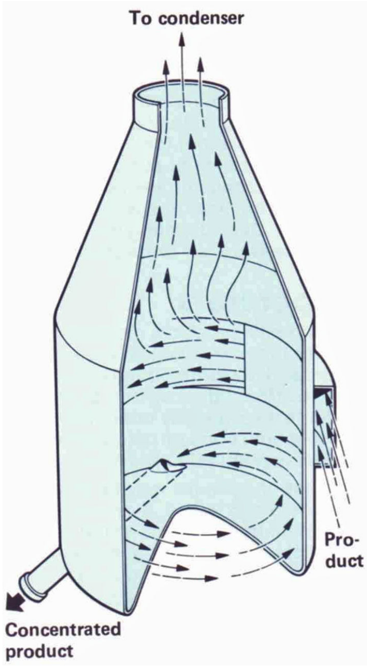


Fig. 2 Vacuum chamber

The resident time in the falling-film evaporator is very short, about 1 minute, as only a small amount of the product is treated at the same time. This is of considerable advantage for the concentration of dairy products which are sensitive to heat treatment.

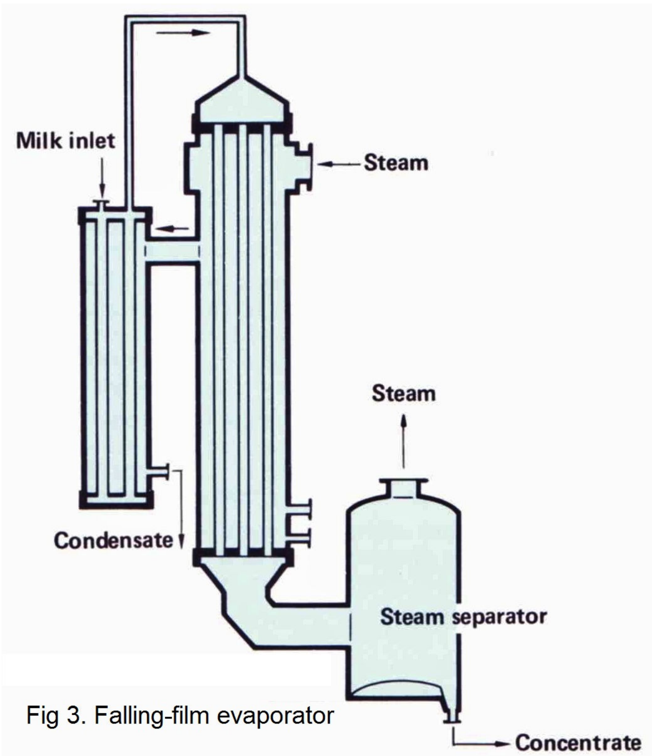


Fig 3. Falling-film evaporator

Multiple-stage evaporation

Multiple-stage evaporation is usually used. The theory is that if two evaporators are connected in series, the second can operate at a higher vacuum (and therefore at a lower temperature) than the first. The vapour generated from the product in the first stage can then be used as the heating medium in the second, which operates at a higher vacuum (lower temperature). 1 kg of water can be evaporated from the product with a primary steam input of about 0.6 kg, also when heat losses are included.

It is also possible to connect several evaporators in series in order to improve the steam economy. This will make the equipment more expensive and more complicated to run. It also involves a higher temperature in the first stage and the total volume of the product in the system increases with the number of stages. This is a drawback when dealing with products that are heat sensitive. However, for reasons of low energy consumption, evaporators with up to seven stages are used in the dairy industry.

Thermocompression

The vapour, generated from the product, can be compressed and used as a heating medium in the evaporator. This improves the thermal efficiency of the evaporator. A thermocompressor is used for this purpose.

Part of the vapour from the vapour separator is supplied to the thermocompressor, to which high-pressure steam (600 - 1 000 kPa) is connected. The compressor uses the high steam pressure to increase the kinetic energy and the steam ejects at high speed through the nozzle. The ejector effect mixes the steam and the vapour from the product and compresses the mixture to a higher pressure. A single-stage evaporator with a thermocompressor is as economical as a two-stage unit without one. Using thermocompression together with multiple stage units optimizes the thermal efficiency.

Fig. 4 shows a two-stage evaporator with thermocompressor for evaporation of milk. The milk is pumped from a balance tank to the first preheater (1) where it is heated to 40 °C and subsequently in the second preheater (2) to 75 °C. The milk then continues to the first stage (3), which is under a vacuum corresponding to a boiling temperature of 70 °C. The water evaporates and the milk is concentrated as the film of milk passes through the tubes.

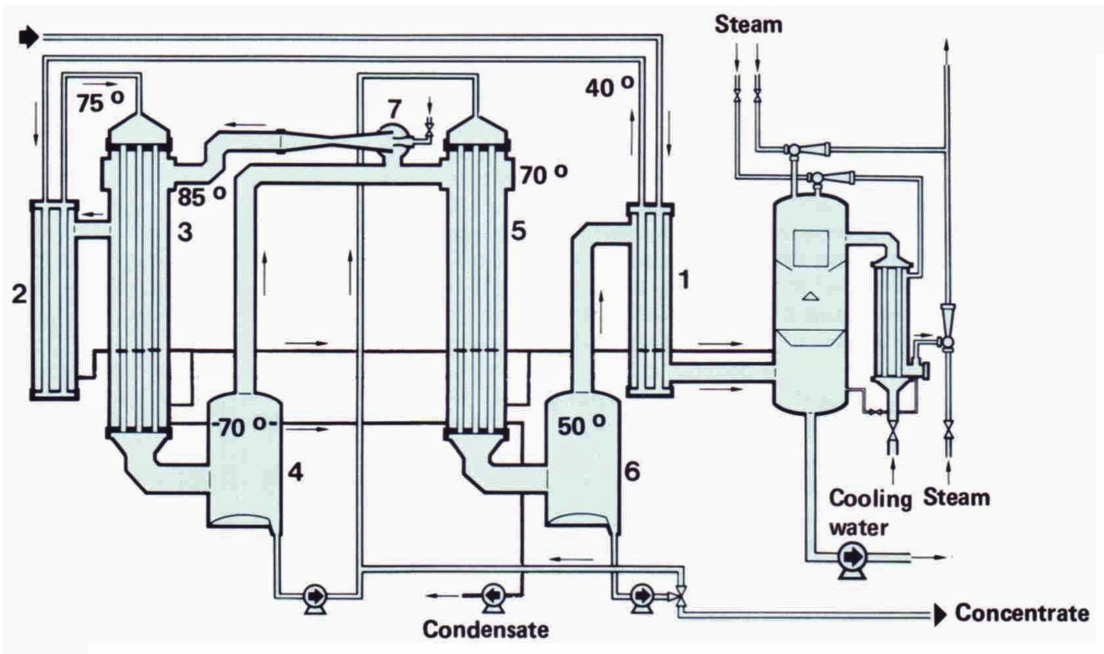


Fig. 4 Two-stage falling-film evaporator with thermocompressor

The concentrate is separated from the vapour in the cyclone (4) and pumped to the second stage (5). In this stage the vacuum is lower and corresponds to a temperature of 50 °C.
After further evaporation in the second stage, the concentrate is separated from the vapour in the cyclone (6) and pumped out of the system. Part of the concentrate is returned to the inlet of the second stage in order to increase the liquid flow rate through this stage, as too low wetting of the heating surfaces can result in incrustation.

By injection of high-pressure steam the thermocompressor (7) increases the pressure of the vapour generated from the product in the first stage. The steam/vapour mixture is then used as a heating medium in the first stage (3).
A modern two-stage falling-film evaporator with thermocompressor requires about 0.45 kg of steam to evaporate 1 kg of water and a three-stage evaporator about 0.25 kg of steam. Without the thermocompressor it would require about 0.60 or 0.40 kg of steam respectively.
The demand on lower energy consumption resulted in plants with more than six stages. For an evaporator the maximum boiling temperature is normally 70 °C on the product side in the first stage and 40 °C in the last.
A temperature difference between 40 and 70 °C makes 30 °C available for the dimensioning of the plant. The more stages, the lower the temperature difference in each individual stage. Temperature difference is also lost in the form of pressure drop and increased boiling point. The sum of these in a multi-stage plant can correspond to a temperature difference of 10 - 15 °C. This requires larger heat transfer surfaces and increased investments. Larger heat transfer surfaces mean increased demands on equipment to distribute the liquid efficiently over the surfaces.
Increased heat transfer surfaces add another, negative factor - the time for the product to pass the heat transfer surface becomes longer. This results in increased holding time for the product in the evaporator.
In a seven-stage evaporator it is possible to evaporate 12 kg water with 1 kg steam. This means that the specific steam consumption is 8%.
How far the concentration process can be forced is determined by product properties, such as viscosity and heat resistance. The concentration of skimmilk and whole milk is usually maximized to 48% and 52% respectively.
The evaporator must have a finishing stage (thickener) in order to be able to produce concentrates with higher solids contents.

Mechanical vapour compression

Contrary to thermal vapour compression, the vapour is drawn out of the evaporator and compressed before being returned to the evaporator when mechanical vapour compression is used.
The pressure increase takes place by means of mechanical energy, used to drive a compressor. No thermal energy is supplied to the evaporator (except steam for pasteurization in the first stage). There is no excess steam which has to be condensed.
In mechanical vapour compression the total amount of steam is circulated in the plant. This makes a high degree of heat recovery possible.

Fig. 5 shows a three-stage plant with mechanical vapour compression. The compressed vapour is returned from the compressor (3) to the first stage to heat the product. The vapour evaporated from the first stage is then used to heat the second stage and the vapour that boils off the product in the second stage is used in the third etc.
In the compressor the steam pressure is increased from 200 to 325 kPa. This means that the condensation temperature is increased from 60 to 71°C. The condensation temperature, 71°C, is not sufficient to pasteurize the product in the first stage. A thermocompressor (1) is therefore installed before the first stage in order to increase the condensation temperature to the required value.
After the vapour separation in the third stage the vapour continues to a small condenser where the surplus steam from the steam injection is removed. The condenser also controls the heat balance in the evaporator. Mechanical vapour compression makes it possible to evaporate 100 - 125 kg water with 1 kW. Using a three-stage evaporator with mechanical vapour compression can halve the operating costs, compared with a conventional seven-stage plant with a thermocompressor.

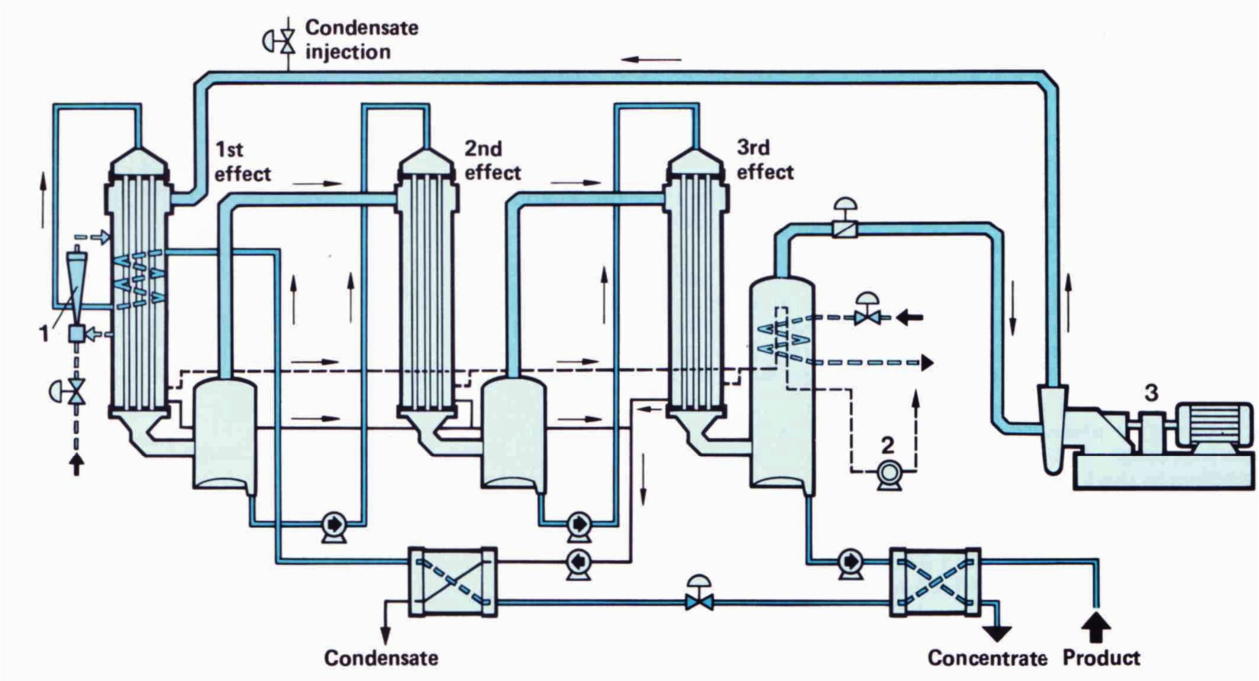


Fig. 5 Three-stage falling-film evaporator with mechanical vapour compressor

Roller or drum drying

In roller drying, the milk is distributed on rotating, steam-heated drums. The water in the milk will evaporate and be removed by a flow of air when it comes in contact with the hot drum surface. The high temperature of the heating surfaces converts the protein to a form which is not easily soluble and which discolours the product. Intense heat treatment increases the water-binding properties of the powder. This characteristic is useful in the prepared-food industry. The distinction between trough-fed and spray-fed roller dryers is based on the manner in which the milk is fed onto the drums.
Fig.6 shows the principle of the trough-fed roller dryer. The pretreated milk is admitted into a trough, formed by the cast iron drums and their end walls. A thin layer of milk in the drums is heated quickly when it comes in contact with the hot drums. The water is evaporated and the layer of milk on the drum dries. This film is continuously scraped off by knives in contact with the periphery of each drum.

Spray drying

The other drying method - spray drying - is carried out in two stages. In the first stage the pre-treated milk is evaporated to a DS content of 45 - 55%. In the second stage the concentrate is pumped to a drying tower for final drying.

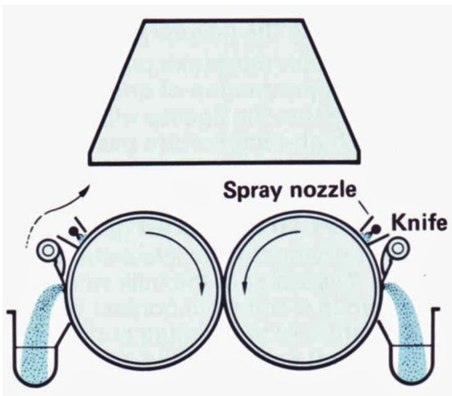


Fig. 6 Principle of the trough-fed roller dryer

This process takes place in three stages:

- Dispersion of the concentrate into very fine droplets.
- Mixing of the finely dispersed concentrate into a stream of hot air which quickly evaporates the water.
- Separation of the dry milk particles from the drying-air. Evaporation is a necessary production stage for high-quality powder. The powder particles will be very small and will have a high air content, poor wettability and a short shelf life if the milk is spray dried without prior concentration. The process will then also be uneconomical.

Falling-film evaporators are generally used for concentration, which is carried out in two or more stages to a DS content of 45 - 55%. The equipment is the same as that used in the production of condensed milk.

Design of the spray dryer

A modern spray drying plant consists of the following components and systems:

- a unit designed for supplying large quantities of hot air
- a milk atomizer
- a mixing chamber in which the hot air is thoroughly mixed with the milk droplets
- a drying chamber
- powder discharge equipment
- a system in which the milk particles are effectively separated from the drying-air
- a powder-conveying and cooling system
- packaging equipment
- equipment for control and supervision of the plant

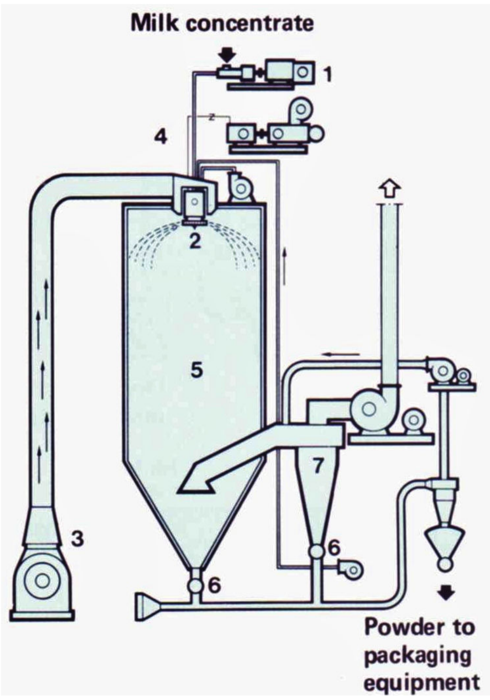


Fig. 7 Spray drying tower for milk powder production

1. High pressure milk pump
2. Atomizing equipment
3. Hot-air supply equipment
4. Mixing chamber
5. Drying chamber
6. Discharge unit
7. Cleaning equipment for the conveying air

Fig. 7. shows another very common type of atomizer, consisting of a rotating disc with passages from which the milk is ejected at high velocity. In this case the properties of the product are controlled by the speed of rotation of the disc. It can be varied between 5 000 and 25000 r/min.

The milk is pumped (1) into the tower by a high-pressure pump and then continues to the milk atomizer (2). The very small milk droplets are sprayed into the mixing chamber, where they are mixed with the hot air.

Air is drawn in by a fan through a filter and supplied to a heater, where it is heated to 150 - 250 °C. The hot air flows through a distributor to mixing chamber 4. In the mixing chamber the atomized milk is

mixed thoroughly with the hot air and the water in the milk is evaporated. The free water evaporates instantaneously. The water in the capillaries and pores must first diffuse to the surfaces of the particles before it can be evaporated. This takes place when the powder slowly settles in the spray tower. The milk will only be heated to 70 - 80 °C as the heat of the hot air is continuously consumed for the evaporation of the water.
During the drying process the milk powder settles in the drying chamber and is discharged at the bottom. Conveying to the filling section takes place pneumatically by means of cooling air which is drawn into the conveying duct by a fan. After cooling, the mixture of cooling air and powder flows to discharge unit 6, where the powder is separated from the cooling air before being filled.
Some small and light particles may be mixed with the drying-air that flows from the drying chamber. This powder is separated in one or several cyclones. After separation the powder is returned to the main stream of milk powder on the way to filling. The cleaned drying-air is extracted from the plant by means of a fan.

Milk atomizing

The more finely dispersed the milk droplets, the larger their specific area will be and the more effective the drying. One litre of milk has a surface area of about 0.05 m^2. If this quantity of milk is atomized in the spray tower, each of the small droplets will have a surface area of 0.05 - 0.15 mm^2. The total surface area of all the milk droplets from the original litre of milk will be about 35 m2. Atomizing therefore increases the specific area by about 700 times.

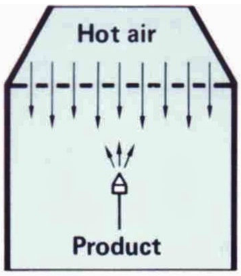


Fig. 8a Stationary counterflow nozzle

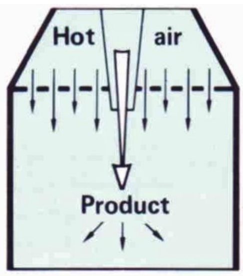


Fig. 8b Stationary nozzle discharging in the direction of the air flow

The design of the atomizing equipment depends on the particle size and the properties required of the dried product. These properties can be granularity, texture, solubility, density and wettability. Certain dryers have stationary nozzles, see Fig. 8. The arrangement in Fig. 8a is used in low spray towers and is located so that the relatively large milk droplets will be discharged in counter flow in relation to the drying-air. A stationary nozzle which discharges the milk in the same direction as the air flow is shown in Fig. 8b. In this case the milk feed pressure determines the particle size. At high feed pressures (up to 30 MPa or 300 bar) the powder will be very fine and have a high density. At low pressures (20 - 5 MPa or 200 - 50 bar) the particle sizes will be larger and free from dust-size particles.

Production of instant powder

Milk powder which will dissolve quickly in water must be instantized - the milk particles must be treated so that they form larger, porous agglomerates. In order to obtain the correct porosity the milk particles must first be dried so that most of the water in the capillaries and pores is replaced by air. The particles must then be humidified, so that the surfaces of the particles swell quickly, closing the capillaries. The surfaces of the particles will then become sticky and the particles will adhere to form agglomerates.
One method of producing instantized powder is to recirculate the dry milk particles back to the mixing chamber containing drying-air and atomized milk particles. As soon as the dry particles are admitted

into the chamber, their surfaces will be humidified by the evaporated water and the particles will swell. The capillaries and pores will be closed and the particles become sticky. Other milk particles will adhere to the surface and agglomerates are formed.

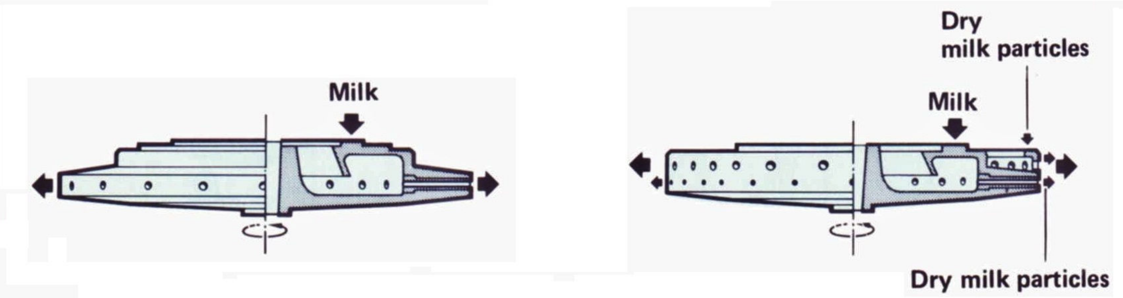


Fig. 9 Rotating disc for atomizing the milk in the spray tower (For instantized powder on the right)

Fluid-bed drying

More efficient instantizing can be obtained by means of a fluid bed of the type shown in Fig. 10. The fluid bed is connected to the bottom of the drying chamber and consists of a casing with a perforated bottom. The casing is spring mounted and can be vibrated by means of a motor. When a layer of powder is distributed on the perforated bottom, the vibrations will convey the powder at a uniform speed along the length of the casing.

The powder from the drying chamber is admitted into the first section, where it is humidified. The vibrations convey the powder through the drying sections, where air at a gradually decreasing temperature is admitted through the powder bed. Agglomeration takes place in the first stage of drying when the particles adhere to each other. The water is evaporated from the agglomerates during their passage through the drying sections. They will have attained the required dryness when they have passed through the fluid-bed casing.

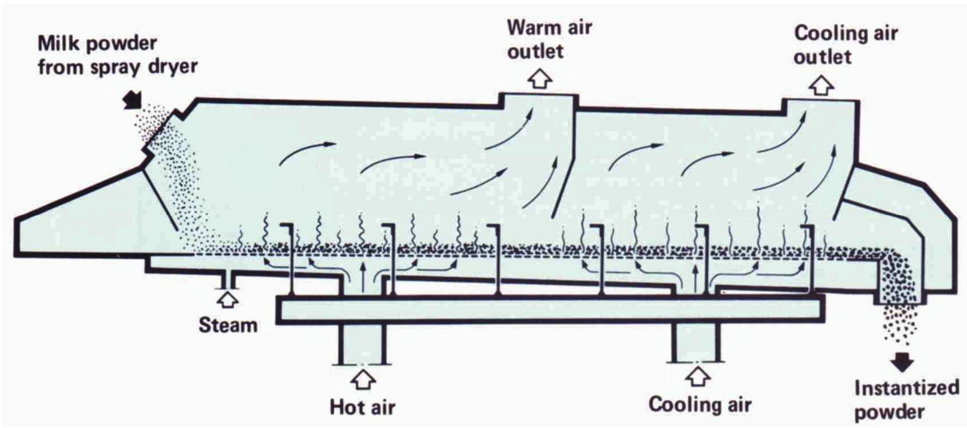


Fig. 10 Vibro-fluid bed for instantizing of milk powder

Any larger particles at the outlet of the dry bed are screened and recirculated to the inlet. The screened and instantized particles are conveyed by the cooling air to a battery of cyclones, where they are separated from the air and packaged.

The drying-air from the fluid bed, together with the air from the spray tower, is then blown to the cyclone for recovery of the milk particles.

Two-stage drying

The combination of a spray tower and a fluid-bed dryer makes it possible to use a two-stage drying process. The temperature of the drying-air extracted from the spray tower is usually used to control the moisture content in the dried product. An increase in the moisture content of 1 % results in a reduction of the air temperature by 5 °C.
In a two-stage drying plant the product leaves the spray tower with a moisture content of 5 - 8%. The final drying in the fluid-bed dryer is carried out at a considerably lower temperature than in the spray tower. The specific energy consumption is therefore 20% lower in the fluid-bed dryer. In addition, the treatment of the product is much more gentle.

Heat recovery

A large amount of heat is lost in the drying process. Some may be recovered in heat exchangers, but the drying-air contains dust and vapour and therefore requires specially designed exchangers.
In several cases a special type of heat exchanger with glass pipes is used, see Fig. 7. The smooth glass surface prevents fouling to a great extent. A CIP system is included in the plant.
The warm air is introduced from the bottom and forced through the glass pipes. The fresh air to be heated flows on the outside of the pipes. By using this method of heat recovery the efficiency of the spray drying plant can be increased by 25 - 30%.
A further possibility is to recover the heat in the condensate from the evaporation plant. The plant operates in parallel with the spray drying plant and such a solution is therefore feasible - with savings of 5 - 8% of the drying costs.

Dissolving the milk powder

One part of powder is mixed with about ten parts of water at a temperature of 30 - 50 °C if ordinary spray powder is to be dissolved. The dissolving time is about 20 - 30 minutes. Longer times are needed at lower temperatures. 8 -12 hours are required if the powder is to be dissolved in cold water.
If instantized powder is used, the required quantity of water is poured into a tank and the powder is then added. The powder will be dissolved after very brief stirring, even if the water is cold. The milk is then immediately ready for drinking.

Filling of milk powder

The types and sizes of packages vary widely from one country to another. The powder is often filled in laminated powder bags with an inner bag of polyethylene. The polyethylene bag is often welded, and this package is practically as air-tight as sheet-metal drums. The most common bag sizes are 25 and 15 kg, although other sizes are also used as it is very easy to vary the weight of the powder in the bags to meet specific customer requirements. Milk powder for households and similar small-scale consumers is filled in sheet-metal tins, laminated bags or plastic bags which, in turn, are packed in cartons.

Changes in the milk powder during storage

The fat in the whole-milk powder oxidizes during storage. On an industrial scale the shelf life can be extended by special pretreatment of the milk, by the addition of anti-oxidants and, in the case of sheet-metal drums, by filling in an inert gas.
Milk powder should be stored under cool conditions and protected against contact with water during storage. Ali chemical reactions in milk powder, at room temperature and with a low water content, take place so slowly that the nutritive value will not be affected, even after years of storage.

11. Ice creams

Ice-cream can be divided into four main categories according to the ingredients used:

- ice-cream made exclusively from milk products
- ice-cream containing vegetable fat
- sherbet ice-cream, made of fruit juice with added milk fat and milk solids-non-fat
- water ice made of water, sugar and fruit concentrate

Water ice is probably the oldest. It is mentioned in Italian literature dating from the beginning of the 16th century. A later development included the addition of dairy products such as milk, cream and eggs. Today, the first two types of ice-cream account for an estimated 80 - 90% of the total world production. The following description is therefore confined to these two types.
The ingredients of ice-cream are fat, solids-non-fat, sugar and water. It also contains various additives - emulsifiers, stabilizers, flavouring and colouring. Accurately metered quantities of the various ingredients are blended into a homogeneous mixture called ice-cream mix. This is fed to continuous freezers of special design, in which air is whipped into the mix. The admixture of air results in a substantial increase in volume; at 100% "overrun", to use a trade expression, the volume of the frozen ice-cream is twice that of the ice-cream mix. The ice-cream is fed from the freezers to various types of filling or proportioning machines for moulding and packaging. Finished products in the form of bars, cups, cones, bricks and larger packs are then hardened and placed in cold storage.

Ingredients

The various ingredients are received, weighed and analyzed in the raw-material reception department, which is usually divided into one section for dry ingredients and one for liquid ingredients.

Fat

Fat, which makes up about 12% of the volume of dairy ice-cream, may be milk fat or vegetable fat. In the first case it may be whole milk, cream, butter or butter oil. Some, or all, of the milk fat in ice-cream may be replaced by vegetable fat in the form of sunflower oil, soybean oil and rapeseed oil. The use of vegetable fat results in a slight difference in colour and flavour compared to milk fat. The difference is hardly noticeable if colouring and flavouring additives are used. The use of vegetable fat in ice-cream is prohibited in some countries.

Solids-non-fat

Solids-non-fat consist of proteins, lactose and mineral salts. They are added in the form of milk powder and condensed skimmilk. For best results the quantity of solids-non-fat should always be in a certain proportion to the quantity of fat. The amount of solids-non-fat should be 11 - 11.5% for the manufacture of ice-cream with a fat content of 12%. Solids-non-fat have a high nutritional value and the ability to improve the texture of the ice-cream by binding and replacing water. They also significantly affect the correct distribution of air in the ice-cream during the freezing process.

Sugar

Sugar is added in order to adjust the solids content in the ice-cream and to give it the sweetness which customers prefer. The ice-cream mix normally contains between 10 and 18% sugar. Many factors influence the sweetening effect and product quality, and many different types of sugar can be used, such as cane and beet sugar, glucose, lactose and invert sugar (a mixture of glucose and fructose). Sorbitol is used in the manufacture of ice-cream for diabetics. Sweetened condensed milk is sometimes used, contributing to both the sweetening effect and the solids-non-fat content.

Emulsifiers

Emulsifiers are substances which assist emulsifying by reducing the surface tension of liquid products. They also help to stabilize the emulsion formed. Egg yolk is a well-known emulsifier, but is expensive and less effective than the most commonly used types, which are mainly non-ionic derivatives of natural fats which have been esterified to give them one or more water-soluble (hydrophilic) radicals bonded to one or more fat-soluble (lipophilic) radicals. The emulsifiers used in ice-cream manufacture can be divided into four groups: glycerin esters, sorbitol esters, sugar esters and esters of other origins. The amount added is usually 0.3 - 0.5% of the volume of the ice-cream mix.

Stabilizers

A stabilizer is a substance which, when dispersed in a liquid phase (water), binds a large number of water molecules. This is called hydration and means that the stabilizer forms a network which prevents the water molecules from moving freely. There are two types of stabilizers: protein and carbohydrate stabilizers. The protein group includes gelatin, casein, albumin and globulin. The carbohydrate group includes marine colloids, hemicellulose and modified cellulose compounds. The stabilizer dosage is usually 0.2 -0.4% by volume of the ice-cream mix.

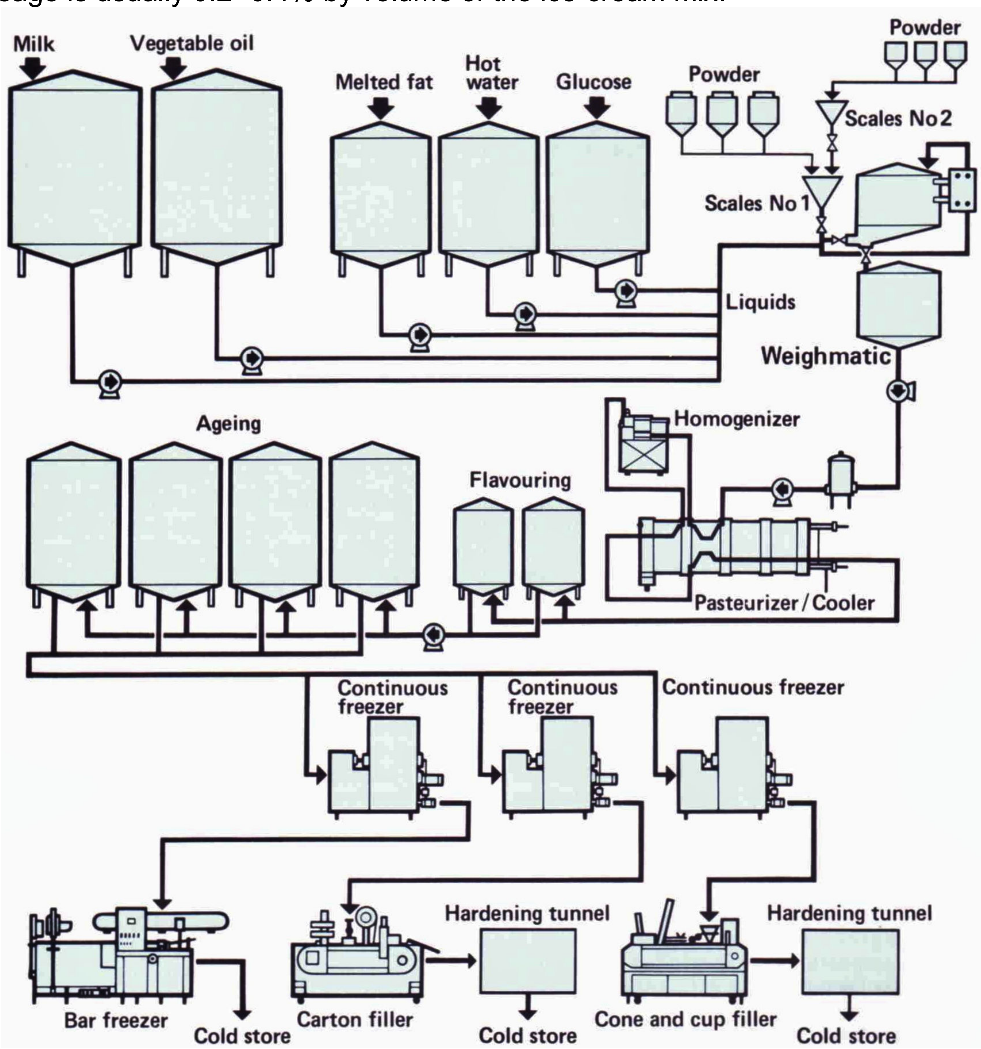


Fig. 1 Ice-cream production plant

Flavouring

Flavouring additives are very important to the customer's choice of ice-cream. The most commonly used flavours are vanilla, nougat, chocolate, strawberry and nut. These can be added at the mixing stage. If flavouring takes the form of larger pieces such as nougat, nuts, fruit or jam, it is added when the mix has been frozen. Cocoa is widely used to give ice-cream bars, cones and bricks a coating of chocolate. For this purpose the cocoa is mixed with fat for example cocoa fat - in order to give the chocolate coating the correct viscosity, elasticity and consistency.

Colouring

Colouring agents are added to the mix in order to give the ice-cream an attractive appearance and to improve the colour of fruit flavouring additives. The colouring agent is usually added in the form of a concentrate. Only approved colouring agents and sterilants may be used.

Reception

Dry products, used in comparatively small quantities, such as whey powder, stabilizers and emulsifiers, cocoa powder, etc., are usually delivered in bags. Sugar and milk powder were previously delivered in containers and the incoming products blown to storage silos with compressed air. Today it is becoming more and more common to deliver bulk materials such as sugar and milk powder in large bags. They are emptied by means of special bag emptying machines. liquid products such as milk, cream, condensed milk, liquid glucose and vegetable fats are delivered by tankers. Milk products are chilled to about 5 °C before storage, whilst sweetened condensed milk, glucose and vegetable fat must be stored at a relatively high temperature (30 - 50 °C) in order to keep the viscosity sufficiently low for pumping. Milk fat is delivered in the form of butter oil or in blocks of butter which are melted and pumped to storage tanks.

Production of ice-cream mix

Fig. 1 shows a general flow chart for ice-cream manufacture. The ingredients come from the raw material stores to the mixing department, where they are weighed and blended to ice-cream mix. The line includes equipment for the batching of the various ingredients, for mixing and homogenization and also for pasteurization, cooling and ripening of the mix. The finished mix is pumped to the continuous freezers and then to the filling machines.

Weighing and mixing

Generally speaking all dry ingredients are weighed, whereas liquid ingredients can either be weighed or proportioned by using volumetric meters. It is very important that quantities are accurate. This is partly because the raw materials are expensive and partly because of quality considerations. A homogeneous end product requires a mix of constant composition. Automatic batching systems have been introduced in order to meet the necessary standards of accuracy.

The weighing units are capable of recombining several liquid and powder ingredients. The product can be heated and/or cooled whilst batching takes place. Weighing takes place by means of three load cells that carry the weighing and mixing unit.

The liquid ingredients are filled into the weighing tank via a battery of two-stage shut-off valves. The liquid ingredients are weighed, one after the other, and the weights recorded. The powder ingredients are then weighed through a hopper, also in sequence, and the weights are recorded. The powder feed is normally arranged by means of auger conveyors discharging into a powder intake with a dust collection filter and a fan.

The powder drops through a grate into a mixer nozzle. The liquid draws down the powder and mixes with it. Clogging and formation of cavities in the powder are prevented by means of a fluidizer nozzle close to the powder outlet. The fluidizer nozzle also ensures uniform powder feed (see chapter

"Recombination of milk").
The mix is mixed and deaerated in the tank by being circulated through a mixing circuit. Circulation may also take place through a plate heat exchanger so that the product is both mixed and heated while batching takes place. The accuracy of this type of equipment is 0.15 - 0.2%.

Mixing

The batched ingredients are blended in special mixing tanks with agitators. The order in which the various ingredients are added is determined by the temperature and solubility. During the mixing process the ingredients are circulated through a plate heat exchanger which heats the mix and also contributes to the mixing effect. The homogeneous mix, which has a temperature of 50 - 60 °C, proceeds to pasteurization.

Homogenization

The ice-cream mix flows through a filter to a balance tank, and is pumped from there to a plate heat exchanger where it is preheated to 73 - 75 °C. The mix is then homogenized at high pressure, 14 - 20 MPa. The purpose of homogenization is to obtain a stable emulsion as well as a uniform size and distribution of fat, emulsifier/stabilizer, and proteins. The result is increased whippability, better body, smoother texture, and improved storage properties.

Pasteurization

After homogenization the mix is returned to the plate heat exchanger and pasteurized at 83 - 85 °C with a holding time of about 15 seconds. The pasteurized mix is then cooled, first regeneratively and then by a cooling medium, to as low a temperature as possible (depending on viscosity, etc.) before being pumped to the ripening tanks.

Ripening

The mix is kept in the ripening tanks for 3 - 6 hours in order for the fat to crystallize and the protein and stabilizers to bind water. This contributes to the consistency of the ice-cream. The ripening tanks are equipped with agitators for gentle stirring. If the tanks are placed in rooms with normal temperature levels they must have jackets for icewater chilling to about 5 °C during ripening. The best solution is to locate the ripening tanks in refrigerated rooms with a temperature of 1 - 2 °C. The tanks can then be simple and uninsulated.

Addition of flavouring and colouring agents

At the end of ripening the mix is pumped to the continuous freezers. If flavouring and colouring agents are to be added, this can be done either in a tank or by direct injection into the line before the freezers.

Continuous freezing

The continuous freezer has two functions:

- to whip a controlled amount of air into the mix
- to freeze the water content in the mix to a large number of small ice crystals

Fig. 2 shows the principle of the continuous freezer. The mix is pumped into a cylinder, which is refrigerated by means of an ammonia jacket. The freezing process is very rapid and the layer of frozen mix on the cylinder wall is continuously scraped off with a rotating knife-equipped mutator inside the cylinder.

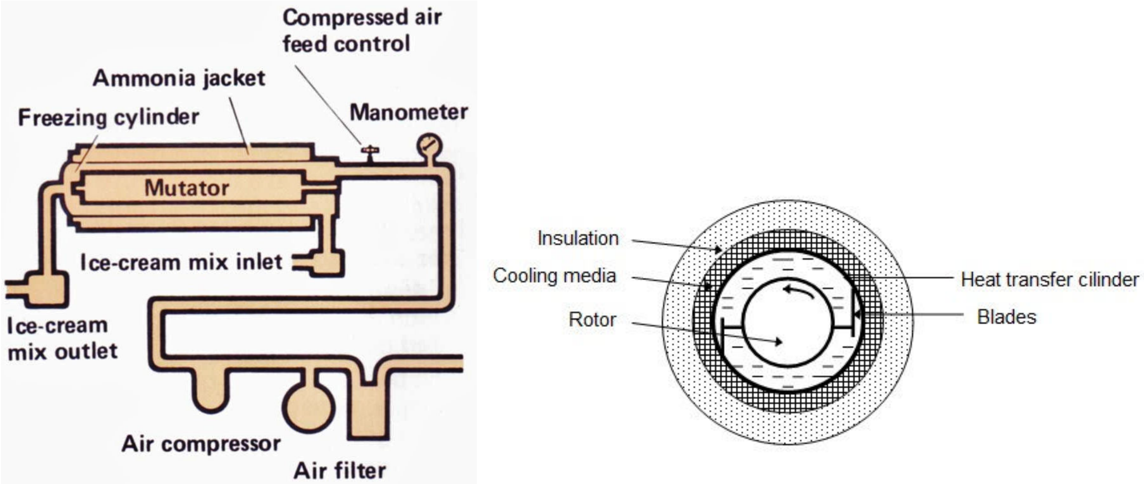


Fig. 2 Continuous freezer

The required amount of air is supplied continuously whilst the ice cream is worked in the freezer, so that the air is worked into the mix at the same time. This gives the ice-cream the desired texture before it is fed from the freezer through a pipe to a forming or filling machine. The ice-cream should have a temperature of -1 to -9 °C at the outlet from the freezer. The temperature depends on whether the ice-cream is to be used for bars, cones, cups or family packs.

Moulding and filling

After leaving the freezer and after the addition of flavouring, if used, the ice-cream proceeds to moulding and filling in the following ways: o filling in large containers

- automatic filling and cartoning in the form of ice-cream bricks. Normal sizes are 1/4 litre, 1/2 litre and 1 litre.
- cone and cup filling
- bar moulding

Ice-cream bars are deep-frozen - hardened to the required finished consistency - in the moulds. Other products - bricks, cones and cups - must be frozen further before being placed in cold storage. This takes place in hardening tunnels.

Large packs

Large packs, ranging in size from 2 to 10 litres, for the catering trade, etc. are often filled manually direct from the freezers. Household packs and moulds for ice-cream gateaux are sometimes filled in the same way. This filling operation is mechanized in high-capacity plants.

Cartons and other household packs

Household packs are filled in special, automatic mass-production machines which perform all the necessary operations: they assemble the cartons, fill and seal the packs or fill and cap the card board or plastic boxes. These machines can be fitted with extra accessories, e.g. for packing Neapolitan ice-cream (with two or three differently flavoured layers) and for adding liquid and solid flavouring ingredients.

Cones and cups

Cones and cups are filled in special machines with capacities that can easily be adapted to the output of the freezers. The cones or cups are loaded in magazines from where they are moved on conveyors through the machine, passing successive stations for filling, decoration and sealing. The machines can be equipped with accessories for different types of ice-cream, e.g. fillers for two or three flavours, for ripple flavouring, for insertion of cylindrical plugs of flavouring ingredients and for adding dry ingredients.

Cone and cup filling machines are available in capacities from 1 000 to 25 000 units per hour.

Manufacture of ice-cream bars

Ice-cream bars are made in special machines with freezing pockets in which the ice-cream is moulded. The pockets are surrounded by a brine solution at a temperature of -40 to -42 °C. Final crystallization takes place and the ice-cream solidifies when the ice-cream from the freezers is introduced into the pockets. A wooden stick is inserted into each pocket when the ice-cream reaches the correct hardness. In order to remove the moulded bars, the pockets are dipped in a bath which melts the surface layer of the ice-cream. The bars can then be lifted out of the pocket.

The bars are often dipped in chocolate or some other coating before being wrapped in paper.

Fig. 3 shows one type of machine for manufacturing ice-cream bars. The freezing pockets are arranged on a turntable over a brine bath. Around the table there are various accessories for filling the pockets, inserting the sticks, withdrawing the finished bars, dipping in chocolate and packaging. The pockets are filled and freezing proceeds while the turntable rotates slowly. The ice-cream has hardened and the sticks are inserted after a certain angular displacement. The table continues to rotate and the ice-cream hardens progressively. Just before the withdrawal point the pockets pass over a warm bath zone where the surface layer melts.

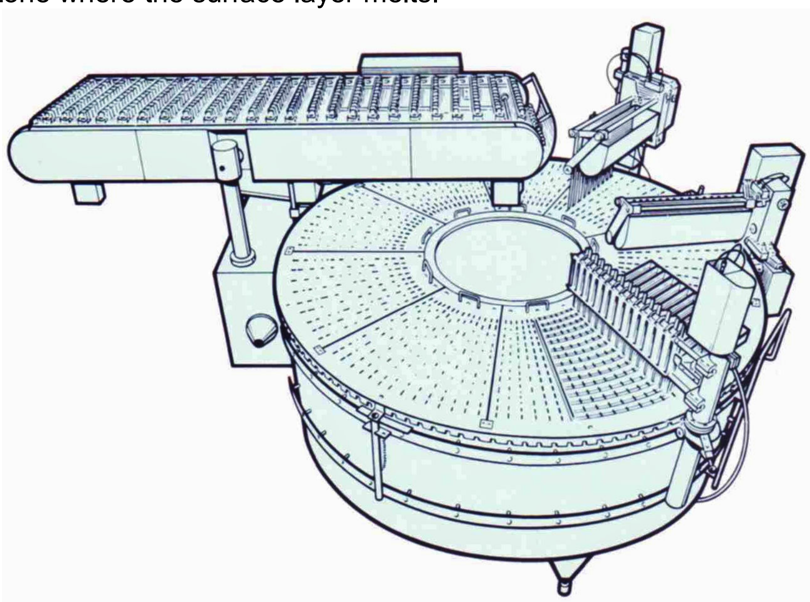


Fig. 3 Ice-cream bar making machine

When the moulded bars have been withdrawn they are dipped in a chocolate or some other coating bath. Surplus chocolate is then allowed to run off and harden before the bars are finally wrapped in paper. From the paper-wrapping machines the bars are forwarded to the cold storage (-25 °C).

Three-dimensional stick novelties

It is now possible to produce novelties in the shape of cartoon figures, cars, or other figures which appeal to children. Fig. 4 shows the production line for the stick novelties.

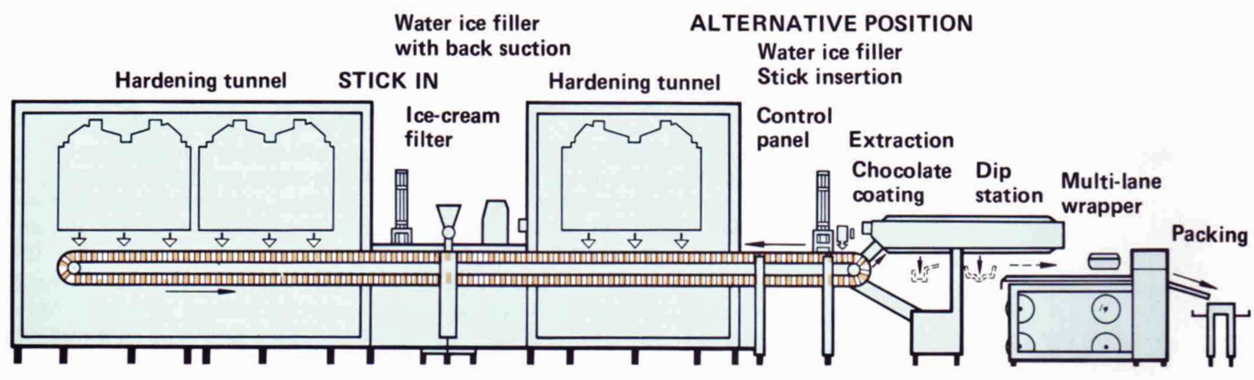


Fig. 4 Production line for three-dimensional stick novelties

The heart of the production system is a mould consisting of two hinged shells. When the shells are closed, the outer shell of the mould follows the contours of the novelty. The ice-cream is filled into the closed moulds and subsequently the wooden sticks are inserted. A spring ensures that the stick is kept in the correct position.
The moulds are then transferred to the freezing tunnel where air with a temperature of -35 °C is circulated at high velocity. After approximately 10 - 15 minutes the product comes out of the freezing tunnel. Defrosting takes place by means of hot water. The two shells are then extracted from each other and the moulds are opened. Finally the extracted stick novelties continue to the packing machine where they are wrapped in paper.

Hardening

Ali ice-cream products, except bars, must be hardened in order to complete the process of crystallization which began in the freezer. Hardening improves the ice-cream for storage and transportation, and gives it the required consistency.
Once again crystallization must be rapid in order to ensure that the crystals are small, as large crystals give a sandy feeling on the tongue. This requires intensive cooling to a temperature of -35 °C or below.
For ice-cream in cartons (half-litre and one-litre packs) contact freezers are often used for the hardening process. A so called hardening tunnel is used for ice-cream in general. This is an insulated cold box with a transportation system to carry the ice-cream products through chambers in which polar air is circulated by powerful fans. A holding time of 50 - 60 minutes is needed to harden half-litre packs to -35 °C; the corresponding time for one-litre packs is 80 - 90 minutes.
After hardening the ice-cream is transferred to a cold storage with a temperature of about -25 °C.

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