Dairy technology in the tropics and subtropics

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J.C.T. van den Berg graduated as a dairy technologist from Wageningen Agricultural University in 1946, and then worked for the Royal Netherlands Dairy Federation (FNZ). From 1954 to 1970 he was dairy advisor for milk and milk products at the Ministry of Agriculture and Fisheries. Thereafter, he worked for the International Agricultural Centre, Wageningen, on assignments concerning dairy development and dairy technology in many countries in Africa, Asia and Latin America; he has lived and worked in Costa Rica, Pakistan and Turkey. From 1982 until his retirement, he was a guest worker at Wageningen Agricultural University, where he lectured on production, marketing and processing of milk in tropical and subtropical countries.

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Contents

Preface

The burgeoning of dairy science and dairy technology has led to an enormous number of articles and books being published on these topics. Unfortunately, all, or at least most of them, focus on one or two subjects only. This form of specialization has diverted attention from the interaction of the various technical and technological aspects of milk handling, milk processing and related subjects. There is a great need for a handbook covering the basics of dairy chemistry, physics and microbiology, in combination with the handling of milk at farm level, the collection and quality control of milk, and the processing of milk into various products, especially for countries in the tropics and subtropics that are developing a dairy industry. This book aims to fill this need. Its contents have been adapted to the conditions prevailing in tropical and subtropical countries. This means that special attention is given not only to small-scale operation, but also to milk produced by domestic animals other than the cow.

Although primarily intended for use as a handbook and a textbook in countries with a developing dairy industry, its comprehensive coverage of dairy technology makes this book useful for readers in countries with a more advanced dairy industry too. Subjects connected with milk production, milk marketing, dairy economics, cost price calculation, dairy and price policy, the establishment of dairy plants, food aid, etc. are not dealt with in this book, but will be covered in a companion volume 'Strategy for dairy development in the tropics and subtropics'.

Much of the material for the present volume was gathered while the author was a dairy development specialist, employed by the International Agricultural Centre, Wageningen, to work in various developing countries. Most of the book was written during a period spent as a teacher and guest worker in the Dairy Section of Wageningen Agricultural University, in Wageningen.

As the book should principally serve as a handbook and a textbook, no references to other publications are included in the text. Relevant literature (mainly other manuals, textbooks, and review articles), is suggested in the 'further reading' at the end of most sections.

Acknowledgements

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The book could not have been completed without the valuable support and information provided by many colleagues, especially those from the Dairy Section of Wageningen Agricultural University in Wageningen and the Netherlands Institute for Dairy Research in Ede. The assistance of the dairy equipment industry in supplying information and material for illustrations is gratefully acknowledged.

A special word of thanks is due to Prof. Dr P. Walstra, Professor of Dairying at Wageningen Agricultural University, who not only took great pains to ensure the publication of this book, but who also read the manuscript closely and made many useful recommendations for improvement.

Abbreviations, symbols

atm	atmosphere (1 atm = 1.013 bar = 101.3 kPa)*
ADMI	American Dry Milk Institute
cal	calorie (1 cal = 4.184 J)*
CFS	continuous-flow sterilization
CIP	cleaning-in-place
°D	degrees Dornic; titrable acidity in degrees Dornic, equal to 0.01% lactic acid (1 °D = 1.11 °T = 1.11 °N = 0.44 °SH)
FAO	Food and Agricultural Organization of the United Nations
FFA	free fatty acids
g	gram
h	hour
°H	degrees of hardness (1 °H ≈ 1 mg $CaCO_3$ per litre of water)
HTST	high-temperature short-time (in pasteurization)
IDF	International Dairy Federation
kcal	kilocalorie = 1000 cal (1 kcal = 4.184 kJ)*
kg	kilogram
LAB	lactic acid bacteria
l	litre
LP	lactoperoxidase (in milk preservation)
ml	millilitre
mm	millimetre
°N	degrees normal (see °D)
ppm	parts per million
QAC	quaternary ammonium compounds
rpm	revolutions per minute
SNF	solids-non-fat
°SH	degrees Soxhlet-Henkel (see °D)
°T	degrees Thörner (see °D)
UHT	ultra-high temperature (in sterilization)
UV	ultraviolet

* For practical reasons, a few common units (atm, cal) have not been conversed into SI units (SI, abbreviation for Système International d'Unités, is a metric system which is gaining popularity throughout the world). Therefore, conversion factors between SI units and other common units used in this publication are given in the list of abbreviations and symbols.

V	volt
WHO	World Health Organization
WPN	*whey protein nitrogen; WPN index: quantity of soluble* whey proteins (mg) available in 1 g of milk powder
μm	micrometre (1 μm = 0.001 mm)

1 Introduction

The conditions for dairying and dairy technology in tropical and subtropical regions vary largely with altitude. At higher altitudes, the conditions in these regions do not differ greatly from those found in temperate climatic zones. Therefore, this book will pay particular attention to dairy technology in the warm tropical and subtropical zones, and less to dairy technology in the temperate zones. Specific problems arise in the production, handling and processing of milk in the warm climates of the tropical and subtropical zones. These problems largely result from the basic differences between the dairy practices in these regions and the advanced dairy industries in the temperate zones. The main differences are:

– Milk from animals other than cattle may be of more importance.

– Animals are often kept not for the production of milk, but for meat or draught, hair or wool, or manure; as a consequence, milk production may be only a sideline activity. The production potential of the animals is low and little attention may be paid to improvement of the genetic characteristics of the animal, and to the stimulation of milk production by improved management and feeding.

– The animals are often kept under nomadic conditions.

– Milk is mainly used for domestic purposes, and surpluses – if any – are converted into traditional products by individuals, or in – often seasonal – dairy plants. This gives rise to special marketing problems.

– Milk production is a seasonal operation, depending on the availability of feed, on climatological conditions and on tradition. The lean/flush ratio of milk production (i.e. the ratio of lowest seasonal milk production to the highest seasonal milk production) is often extreme. In general, production is highest during and shortly after the wet season. In certain areas, however, the natural pastures are flooded during the wet season and the animals have to migrate to poor grazing areas. After the wet season, flooded areas dry out and provide excellent grazing lands.

– If hygienic standards of production and handling are poor, the keeping quality of milk will be very poor at the high ambient temperatures and there will be a very high risk of spoilage. This is reflected in the processing techniques. As a consequence, the compositional and organoleptic properties of tropical milk products may differ from similar products manufactured in cooler climates. This is especially true in the case of indigenous products produced at the farm or in small-scale plants in villages. As soon as milk processing is taken over by industrial dairy plants, more advanced techniques are introduced and a certain 'world-wide' uniformity of products can be observed.

– Poor road conditions, unreliable electricity supply, a lack of good quality water, low milk-production density (i.e. the milk production per square kilometre), and the poor keeping quality of the milk restrict the technological and economic possibilities of commercialization of milk.

– Low standards of living restrict the demand for dairy products. Consequently, large-scale production is not stimulated, particularly because the costs of producing, processing and marketing the milk tend to be high.

– In many tropical countries with an underdeveloped dairy industry, the industry has not been organized. Studies on the specific problems of production, processing and marketing in these countries only assumed significance after World War II, because only since then have serious attempts been made to organize an industrial approach. However, in many cases the organizational and marketing experience obtained in the temperate zones and, to a lesser extent, the technology from these areas have been applied in tropical and subtropical countries. In many cases this has led to disappointing results.

Apart from the points mentioned above, religious, social, dietary and traditional aspects may play an important role in the development of the dairy industry in different parts of the world.

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2 Milk production and milk properties

2.1 Milk production

All mammals produce milk but only few species produce milk that is utilized by man. The most important are:
- cattle,
- buffalo,
- sheep,
- goat,
- horse,
- ass,
- camel.

The quantities of milk produced by the various species differ markedly, but individual animals also show wide variations in production within one species, mainly depending on:
- domestic purpose,
- breed and genetic quality,
- environmental conditions,
- physiological condition,
- level of management.

Mares, asses and camels are principally kept as draught, pack or riding animals. Milk production is secondary and milk is only incidentally consumed by man, although in some areas the milk of these animals is highly appreciated and may be used for the manufacture of special fermented milks, such as koumiss (originally produced from mare's milk).

Real milch animals are only found amongst cattle, buffaloes, sheep and goats, although many breeds of these species are dual- or even triple-purpose animals which are mainly kept for the production of meat and wool or hair, and often for their manure. Cattle and buffaloes are often kept as draught animals.

Buffaloes are mainly found in tropical and subtropical areas. They are believed to originate from Southern Asia. Some races are considered to be fairly good milk producers, but on average their yields vary between 500 and 1000 l per production period.

Some breeds of cattle, sheep and goat have been specially bred for milk production. The real milch animals principally originate from the temperate zones, although good indigenous milch breeds are found in the tropics and sub-tropics. The latter, however, generally belong to the dual- or triple-purpose animals, and thus give much lower yields.

Generally, but specifically under tropical conditions, the production figures of animals, whether indigenous or not, do not depend solely on the genetic quality of the breed, but also – and often even to a larger extent – on environmental conditions. Underfeeding has a pronounced effect on milk production; first, the quantity of milk decreases, often accompanied by a higher fat content. Prolonged underfeeding also results in a decreasing fat content. If milk production falls because of temporarily poor feeding conditions, it is unlikely to recover in the same lactation. When transferred from the temperate zone to tropical areas, the yield from very productive animals usually drops. This is because of differences in climate, feeding, management, lack of resistance to tropical diseases, etc. On the other hand, comparatively low-yielding indigenous animals normally kept under unfavourable conditions in the tropics may show a distinct increase in production after these conditions have been improved.

Statistics on milk production vary greatly, depending on whether they are given per lactation or per year. A lactation period is the period between parturition and final 'drying off' or cessation of milking. The average annual milk production depends on the interval between two parturitions and the milk production in one lactation.

Published data on milk production are often misleading because:
– they are from farms and institutes where the production is controlled. Such farms or institutes usually keep very productive animals under conditions of better management than those prevailing on ordinary farms;
– they are often extrapolated to periods of 300 or 305 days, although the actual production period is much shorter.

The production figures of the major tropical breeds of the most important species can be found in relevant handbooks.

Milk production is not constant during the entire lactation period. Production usually increases slightly during the first days, weeks or even months of lactation, but thereafter it will gradually decline until the cessation of milk production. The duration of the lactation period mainly depends on the interval between two parturitions, genetic properties, environmental conditions and management.

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2.2 Composition of milk

Milk is the first food the newly born human being or mammal receives. To serve its purpose it is a food that contains all the nutrients the newly-born requires. But beyond the suckling period it is still the most complete food for human beings and mammals. Some of the essential minerals and vitamins such as iron and vitamin D are not present in sufficient amounts or in optimum proportions to fulfil the requirements for complete nutrition. During the first period of its life, the young animal makes up for the shortage of certain nutrients in milk by exploiting the reserves it receives from its mother at birth, which are normally sufficient until its diet includes other foods. To make the nutrients easily consumable and digestible they are available in a liquid state, partly as a solution, partly as a dispersion or suspension.

There is a wide variation in the composition of milk of the various mammals, but basically they contain the same components. These components are:
- water,
- milk fat,
- milk proteins,
- lactose,
- minerals,
- citric acid,
- vitamins,
- enzymes,
- other components.

Data in publications about chemical and physical characteristics of milks from various species and breeds should be accepted with reservations. The physiological conditions of the animals and the level of management under which they are kept are seldom specified, neither are the conditions of sampling or methods of analysis always mentioned. Furthermore, the stage of the lactation period has a marked influence on the composition and properties of milk. Consequently, there is often little uniformity in data found in literature, and information from various sources may even be contradictory. Most research has been done on cow's milk. Far less work has been done on buffalo's and goat's milk, but information on ewe's milk is scarce.

High temperatures may lower the milk yields of mammals imported from temperate zones, but usually do not significantly affect the composition of the milk.

Representative values for some of the major constituents of good quality milk from different species are given in Table 1. Note that these data are averages. There will be considerable variations between breeds and between individual animals of the same breed. Similar variations are found in minor constituents (not mentioned in the table). The chemical properties of the constituents of various milks may differ markedly as well.

All this leads to variations in the physical properties of milks from various sources. This is important from a nutritional point of view and has consequences for the dairy processing industry. In this book, differences in the composition and properties of various milks and the resulting implications for the dairy processing industry will be highlighted.

Table 1 clearly shows that the composition of the milk of non-ruminants differs distinctly from the milk of ruminants; this may be partly explained by differences in the digestive system of the two groups. Moreover, there are grounds for believing that the composition of milk is related to the rate of growth of the suckling young. But although the milk of the dairy buffalo contains more of the protein and calcium phosphate – essential for the growth of the calf – than cow's milk, buffalo calves grow less quickly than the calves of dairy cows.

Milk produced by diseased animals often shows abnormalities. Milk derived from animals suffering from mastitis may show a lower solids content, although the salt content may be higher.

To supply the needs of the newly born animal, the composition and the general properties of the first secretions after parturition – the colostrum – are very different from normal milk. The colostrum of all domestic animals is characterized by a high

Table 1. Broad survey of the composition of milk (g/100 g) of different species. (After various sources).

Species	Fat	Casein	Whey proteins	Lactose	Ash
Human	4.6	0.8	0.7	6.8	0.2
Cow					
– *Bos taurus*	4.2	2.6	0.6	4.6	0.7
– *Bos indicus*	4.7	2.6	0.6	4.7	0.7
Buffalo	7.8	3.2	0.6	4.9	0.8
Goat	4.5	2.6	0.6	4.4	0.8
Sheep	7.6	3.9	0.7	4.8	0.9
Horse	1.6	1.3	1.2	6.2	0.4
Ass	1.5	1.0	1.0	7.4	0.5
Camel	4.0	2.7	0.9	5.4	0.7

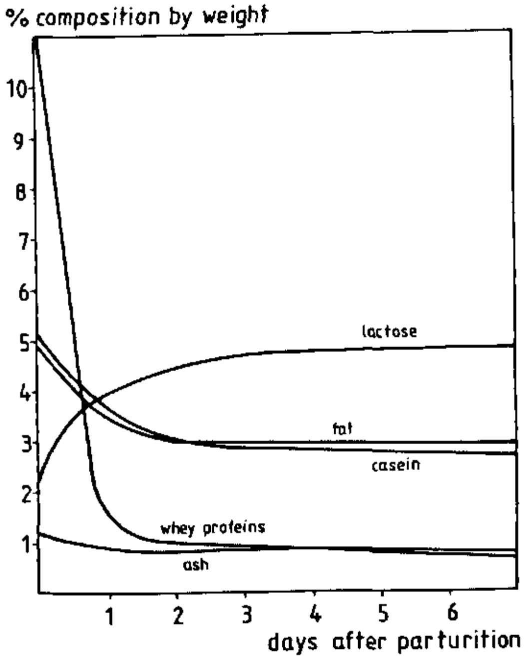

Fig. 1. Changes in the composition of cow's milk after parturition.

density and a high viscosity. The total solids content of colostrum is much higher than that of milk, although the lactose content is generally lower. The fat content may be higher or lower. The protein content, in particular the content of the easily-digestible whey proteins, is remarkably high. Finally, the content of minerals and some vitamins is also higher. Colostrum is of special interest because it also contains antibodies to protect the young animal against infectious diseases.

The composition of colostrum changes quickly during the first five days of lactation, but it may take ten days or more before the composition is 'normal' (Figure 1). There are considerable differences in the composition of colostrum and in the change-over from colostrum to normal milk, even between the individual animals of one breed.

The difference in the composition of colostrum and normal milk results in differences in certain physical properties. Of these, the lower heat stability and the high content of whey proteins in colostrum make it unfit for processing. For this reason, dairy plants do not accept colostrum.

After the rapid decrease in the solids content of colostrum, the fat and protein content of the milk of our domestic mammals diminishes slowly, reaching a minimum in full lactation. The fat, protein and salt content of the milk increase again in a later stage of the lactation as the daily milk yields fall off. The moment at which the lowest point of production is reached depends on the length of the lactation, but seasonal and other external influences may play their part (Figure 2).

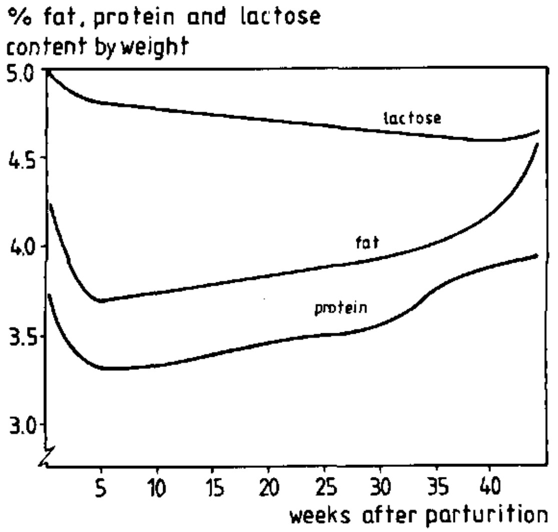

Fig. 2. Changes in the composition of cow's milk during lactation.

2.2.1 Water

Water is the principal constituent of milk. It is the carrier of all other components.

Milk plasma consists of the fat-free part of milk. It is very similar to machine-skimmed milk (Section 5.3). Thus, full cream milk is a dispersion of the milk fat in the plasma.

The serum of milk consists of the solution that remains after the fat and the casein have been removed. It is very similar to whey, the aqueous byproduct of cheesemaking (Section 9.4), although whey still contains some of the milk fat and casein originally available in milk.

2.2.2 Milk fat

Milk-fat globules

Milk fat is present in milk in the form of very small globules. The globules are dispersed in the plasma. They vary from 0.1 to 15.0 μm in diameter; the average size is about 3 μm, but differs markedly between species and breed of milch animal. Ranking the milk of the four most important species of domestic livestock by average size of globules gives: buffalo's milk, cow's milk, goat's milk and ewe's milk[1]. Comparing breeds,

[1] Often, the term sheep('s) milk is used, instead of ewe('s) milk.

milks with a high fat content will usually contain larger globules than milks with a low fat content. Towards the end of the lactation, there is a tendency for the animal to produce smaller globules. The globules at the beginning of lactation are comparatively large.

Each globule is surrounded by a membrane consisting of a thin layer of proteins and phospholipids and a number of other compounds. The membrane protects the globule, preventing it from coalescing with other fat globules. Without such a protective layer the globules would unite and form large masses of fat. Some of the copper contained in the milk and about three-quarters of the phosphatase enzyme is concentrated in the membrane.

Composition of milk fat

The term 'milk fat' should only refer to the pure fat, but since the fat is associated with other fat-like substances, such as lecithine and cholesterol, the term 'lipids' is often used for all fatty components that can be extracted from the milk by ether. They include pure milk fat, phospholipids, vitamins and certain other compounds.

Pure milk fat consists of glycerol (12.5%) and fatty acids (87.5%). The carboxyl groups of the fatty acids are bound with one of the three alcoholic groups of the glycerol by reaction (and liberation of water), thus forming glycerides (Figure 3). Most of the glycerides are triglycerides, in which case the glycerol is combined with three fatty acids, but about 0.3% of the glycerides in cow's milk are di- or mono-glycerides, in which case the glycerol is combined with only two or one fatty acid.

All fatty acids consist of a chain of carbon atoms (–C–) to which hydrogen atoms (–H) are linked. At the end of the chain one carboxyl group (–COOH) is found. Almost all fatty acids contain an even number of carbon atoms. They are characterized by:
- the number of carbon atoms,
- the number of double bonds.

Three groups of fatty acids can be distinguished: short-chain fatty acids with 4 to 8 carbon atoms, medium-chain fatty acids with 10 to 14 carbon atoms and long-chain fatty acids with 16 and more carbon atoms.

Milk fat from ruminants has a high content of short-chain fatty acids; these are built up in the mammary gland from acetic acid plus two carbon atoms, derived from the rumen fermentation. Human milk fat and milk fat from other non-ruminants does not have fatty acids with less than 10 carbon atoms, because acetic acid is not available and glucose with six carbon atoms is the basic material for fatty acid production. The milk fat of sheep's and goat's milk is characterized by a higher content of the short- and medium-chain fatty acids than the fat of cow's and buffalo's milk. The last-mentioned is particularly rich in long-chain fatty acids.

The fatty acids with 10 or fewer carbon atoms, viz. butyric, caproic, caprylic and capric acid with 4, 6, 8 and 10 carbon atoms, respectively, are liquid at room tempera-

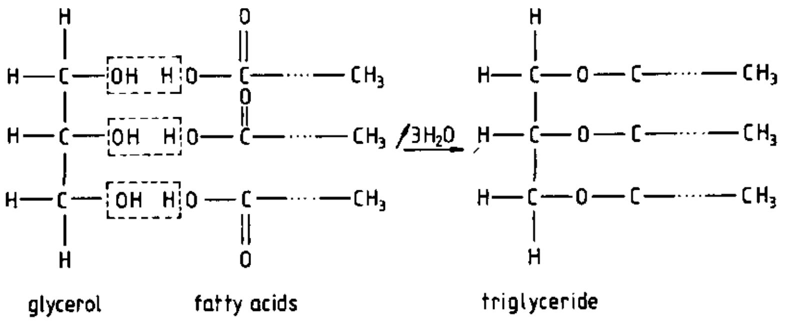

Fig. 3. Structure of milk fat.

ture. They are responsible for causing rancidity in milk and milk products if the milk fat decomposes or hydrolizes.

The other fatty acids with a higher number of carbon atoms are either saturated or unsaturated. In the saturated fatty acids, all adjacent carbon atoms are bound by a single link, and all the carbon atoms are saturated with hydrogen atoms. The most important saturated fatty acids are lauric acid, myristic acid, palmatic acid, stearic acid and arachadic acid, with 12, 14, 16, 18 and 20 carbon atoms, respectively.

In the unsaturated fatty acids at least two adjacent carbon atoms are linked with a double bond. Each of the adjacent carbon atoms is missing one hydrogen atom (Figure 4). Almost all unsaturated fatty acids belong to the mono-unsaturated group, of which oleic acid with 18 carbon atoms is the most important. In poly-unsaturated fatty acids, two or more double bonds are found. These acids are quantitatively of far less importance; linoleic acid (two double bonds) and linolenic acid (three double bonds) belong to this group. Unsaturated fatty acids are fairly easily oxidized by binding oxygen at the carbon atoms linked with a double bond. The unsaturated fatty acids are all liquid at room temperature.

Unlike butter, most other fats – including normal margarine – contain few or none of the fatty acids with low numbers of carbon atoms. The proportion of these fatty acids in the milk fat of each species is fairly constant.

In addition to glycerides, milk fat is associated with small amounts of other compounds. The most important are free fatty acids (FFA), phospholipids, cholesterol and vitamins.

Free fatty acids (FFA). Milk fat in freshly drawn milk contains traces of free fatty acids. These are fatty acids not linked with glycerol. During storage their content may increase considerably by enzymatic hydrolysis of the fat, that is splitting of the fat and addition of water, thus liberating fatty acids (compare Figure 3). The acidity of the fat increases as a result of hydrolysis, and a rancid flavour develops.

Phospholipids. Phospholipids, also known as phosphatides, differ from milk fat in

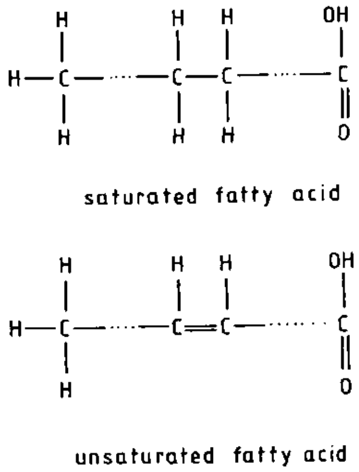

Fig. 4. Diagrammatic representation of fatty acids.

that one of the three alcoholic groups of the glycerol is linked with a phosphoric acid and an organic base group instead of with a fatty acid. Lecithine is an important phospholipid in milk.

The phospholipids are mainly concentrated in the membranes of fat globules, where they act as emulsifying agents, helping to keep the fat globules dispersed in the milk plasma. Buffalo's milk, with its large fat globules, has less membrane material than cow's milk, and is consequently less rich in phosphatides, although the fat content is higher.

Since the phospholipids are rich in unsaturated fatty acids, they easily give rise to oxidized flavours. The lower phosphatide content of buffalo's milk might explain why the fat in buffalo's milk is more resistant to oxydation than – for instance – the fat of cow's milk. Copper concentrated in the membranes of fat globules acts as a catalyst in the oxidation of the unsaturated fatty acids of the phospholipids, which in turn are believed to activate the oxidation of the pure milk fat.

Buttermilk obtained by churning cream has a high content of phosphatides and consequently the dried product has excellent emulsifying properties. Dried sweet-cream buttermilk is used in the food industry; it is an excellent ingredient in ice-cream mix. Moreover, since phospholipids have a 'creamy flavour', buttermilk powder may contribute to the taste of products to which it is added.

Cholesterol. Cholesterol is an alcoholic compound of complex structure. In milk, most of it is found in the fat globules.

Vitamins. Milk is an important source of vitamins; some are associated with the plasma, others with the fat. The latter include the vitamins A, D, E and K (Section 2.6.5).

Physical properties of milk fat

As a result of the complexity of the glyceride system, milk fat has a wide melting-range instead of a distinct melting point. In body-warm milk, all fat is liquid.

The melting point of most of the component glycerides of the fat in cow's milk lies between 20 and 33 °C, but glycerides with much higher and lower melting points are found. Although considerable amounts of glycerides are still liquid at a temperature of 20 °C and lower, milk fat as such is considered to be solid at that temperature. If the temperature of solid milk fat is increased slowly, the glycerides with a lower melting point will become liquid first. The other glycerides will become liquid at the moment the temperature reaches their melting point. At a certain moment the milk fat is considered to be liquid, although not all glycerides have reached their melting point. The fat in cow's milk is considered to become completely liquid at about 33 °C. In general, the melting point of the milk fat mainly depends on the composition and the kind of feed the animals eat.

Differences in the melting-range of milk fat are found between species and breeds. Because of the higher content of long-chain fatty acids, the melting range of buffalo's milk fat lies at a higher temperature (about 6 °C) than cow's milk fat. This has consequences, particularly for the buttermaking process.

Although there is a wide variation in the composition of the triglycerides and their melting points, the composition of the milk fat is not the only factor that controls its structure and firmness at a certain temperature: the cooling rate and the resulting crystal structure are also important. At a rapid cooling rate, small fat crystals are formed, making the fat comparatively hard (or firm). A slow cooling rate or a stepwise cooling results in larger crystals, making the fat comparatively weak (or soft).

The effect of differences in the glyceride composition of milk fat on the firmness of butter decreases with increasing temperature.

If the milk fat is cooled below its final melting point, it may remain liquid for some time. So-called 'under-cooled' fat can be induced to solidify by vigorous agitation, for instance by churning the cream for butter making (Section 8.3).

2.2.3 Milk proteins

Milk contains two different groups of proteins. These are:
- the casein complex, present in the milk as a colloidal suspension;
- the whey proteins, present in the milk as a solution.

In addition to these groups, very small amounts of other proteins or protein-like compounds are found in milk. Amino acids are the principal building materials of the proteins.

Casein complex

The proteins in milk consist for about 80% of casein, which is made up of a number of components, together forming complex particles or micella. One of the components, the κ-casein (kappa-casein), is believed to be concentrated on the surface of the micella, performing a stabilizing function.

Casein is linked with cations, mainly calcium, thus forming a caseinate. Other salts, mainly calcium phosphate ('colloidal phosphate'), are associated with the caseinate linking the various casein compounds, thus giving the micella their structure. The whole structure of casein components, calcium phosphate ('colloidal phosphate') and other salts is known as the calcium caseinate-calcium phosphate complex or, for short, the casein complex.

Casein is not significantly altered by normal pasteurization procedures. Prolonged heating at high temperatures will definitely change the properties of the casein complex and decompose certain amino acids. These changes are organoleptically observed as cooked flavour and brown colouration; physically they are observed as changes in the heat stability and rennetability of the milk.

The composition of the casein complex varies within and between species. Thus the procedures to be followed for the manufacture of certain dairy products vary according to the kind of milk being used. The micella in buffalo's milk, for instance, are much larger than those in cow's milk; moreover, they contain more calcium and phosphorus.

There are two different methods of precipitating the casein:

- by souring the milk either by the direct addition of acid or by bacterial acid production;
- by coagulation after the addition of certain enzymes (Section 9.2).

Different names are used for the various states in which casein can exist, namely:

- as it occurs in milk, whether raw or after heat treatment (the calcium caseinate-calcium phosphate complex or, for short: casein complex; see earlier);
- as it is precipitated by enzymes (sometimes called the paracaseinate complex);
- as it is precipitated by acid (acid casein).

In this book the term 'casein' will be used for all varieties, unless this leads to confusion, in which case the appropriate name will be used.

Whey proteins

Provided the milk has not been subjected to heat treatment, the water-soluble whey or serum proteins are retained in the milk serum after the casein has been precipitated by acid or by rennet. The part of the κ-casein available in whey obtained by curdling the casein by rennet is not considered to belong to the whey proteins proper.

The most important whey proteins belong to the albumins, the globulins and the immunoglobulins; small amounts of other whey proteins are also present. Immunoglobulins are antibodies. The agglutinins responsible for the creaming of cow's milk belong to this category (Section 5.3).

Most of the whey proteins react with casein when the milk is heated to temperatures of 63 °C and above. The higher the temperature and the longer the treatment, the more of these proteins will associate with the casein micella. At normal HTST pasteurization (Section 6.2) only negligible quantities are denaturized in this way.

Non-protein nitrogenous compounds

The presence of nitrogen is one of the main characteristics of proteins, but traces of non-protein nitrogenous products are also found in milk. They are probably by-products of protein metabolism.

2.2.4 Lactose

Lactose or milk sugar is a disaccharide, composed of the monosaccharides dextrose (glucose or corn sugar) and galactose. Milk sugar is not found in any other natural product. Apart from this sugar, only traces of other carbohydrates, monosaccharides, are found in milk. Sucrose is much sweeter than lactose.

Lactose in milk may be fermented by micro-organisms. Lactic acid bacteria (LAB) convert lactose into lactic acid and a number of by-products until the accumulated acid prevents further reproduction and activity of the bacteria. At this point, 15 to 40% of the lactose has been fermented, depending on the type of bacteria.

2.2.5 Minerals

After the water in milk has been driven off and the residue incinerated, a nearly white ash will be left. This ash contains the mineral substances, but as a result of the chemical changes during incineration, the residual compounds differ completely from those found in the original milk. Some of the minerals in the ash are derived from the salts dissolved in the milk, but others are derived from the insoluble components, mainly the casein complex, which contains calcium, phosphorus and sulphur.

The seven major mineral salt elements in the ash are:
- chloride,
- potassium,
- calcium,
- phosphate,
- sodium,
- sulphate, and
- magnesium.

Apart from these elements many trace elements are found, such as zinc, copper, iron, manganese, etc.

The ash content of the milk of different species varies considerably. The ash content of milk of ruminants is mostly higher than that of non-ruminants. Within species, considerable differences are found. In goat's milk the ash content may vary from 0.70 to 0.85%. At the end of the lactation period the ash content of milk is generally high. It may even give the milk a salty taste.

2.2.6 Citric acid

Small amounts of citric acid are found in milk. They are important for the stability of the casein complex. Furthermore, citric acid plays an important role in the production of diacetyl, the principal flavour compound in butter produced from cultured cream.

2.2.7 Vitamins (other than those associated with the milk fat)

Apart from the vitamins dissolved in or associated with the milk fat, all water-soluble vitamins are found in the plasma of milk. The most important ones are those belonging to the vitamin B complex and vitamin C.

Vitamin B complex. More than 10 different constituents belonging to the vitamin B complex have been identified in milk. However, with the exception of vitamin B_2 (riboflavin), they are present in small amounts. B vitamins are produced in the rumen of ruminants.

Vitamin C. Milk is an important source of vitamin C (ascorbic acid). Unfortunately, vitamin C quickly oxidizes, in particular in the presence of copper, to a product that is biologically inactive. If large quantities of ascorbic acid are added to milk (e.g. at least 50 ppm in milk fortified with vitamin C), the acid may act as an anti-oxidant.

2.2.8 Enzymes

Enzymes are catalytic agents, which activate chemical reactions without being used up or destroyed themselves. They are either proteins or proteins associated with an inorganic compound. Their action is very specific, many of them having a hydrolysing function. Most names of enzymes indicate the compound upon which they are active, because they are formed by adding the suffixase to the name or the first part of the name of that particular compound. For instance: the name of the enzyme lipase is obtained by adding -ase to lip- (the first part of the word 'lipid', which is the name of the compound that is hydrolysed by the enzyme lipase).

It is not clear whether the enzymes in milk have a nutritional function. Nevertheless, they are extremely important for the dairy industry, because the activity of some of them leads to undesirable changes in milk and milk products, whereas the action of others is required to produce essential milk products.

Several laboratory tests are based on the presence or the activity of certain enzymes.

Lipases

Lipases are responsible for the rancid flavour in milk and milk products. They hydrolyse glycerides, thus liberating free fatty acids (Figure 3). This process is called lipolysis. Lipase enzymes are still active at temperatures as low as 4 to 5 °C. Most of them are destroyed at normal or slightly increased HTST pasteurization temperatures, but rancidity already developed in raw milk will not be removed during pasteurization.

There are three categories of lipase:

- bacteriological lipase,
- naturally active lipase,
- induced lipase.

Bacteriological lipases are produced by micro-organisms; naturally active and induced lipases are excreted with the milk.

Bacteriological lipase. Certain micro-organisms are able to produce lipases, either in raw milk or in pasteurized products after recontamination. Of special importance are psychrotrophic bacteria, which may develop in deep-cooled milk. Many of them are able to produce very heat-resistant lipases (Section 6.5). Since the bacteriological development in deep-cooled milk proceeds very slowly, there is little danger of these enzymes occurring during the first two days of storage.

Lipases in pasteurized products, or products manufactured from pasteurized milk, will be responsible for the production of rancid flavours, which in some cases are desirable (for instance, in some types of cheese) and in other cases are undesirable (for instance, in butter and evaporated milk). It should be mentioned, however, that many consumers do not object to a more or less pronounced rancid flavour in butter and certain other dairy products.

Naturally active lipase. Naturally active lipase may act spontaneously in milk in the presence of certain catalysing organic substances. The presence of these substances is the critical factor, rather than disturbances or damages of fat globule membranes (compare induced lipase). Normal milk does not contain the activating substances (lipoproteins).

Induced lipase. Lipase is also found in the plasma of milk, where it is believed to be associated with the casein complex. The term 'induced lipase' is misleading, because it is not the lipase that must be induced, but the conditions in the milk must be induced in such a way that the enzyme can become active. This induction consists of disturbing or damaging the fat globule membrane in such a way that uncovered fat is formed, which will immediately be covered again with milk solids available, mainly from the casein complex. The enzyme has the ability of penetrating the newly formed casein membrane, thus gaining access to the fat to start its lipolytic activity.

Prevention of inducement is the best way of avoiding the development of rancidity. The principal causes of inducement are:

- Agitation of milk in the presence of air, causing foam. Such agitation may occur whenever milk is pumped or stirred. Pumping the milk through the piping system at the farm or the collection centre, especially in ascending parts of the pipe lines (risers) and in sharp bends may contribute to the activity of the enzyme in the milk.
- Homogenization of raw milk, which increases the number of fat globules and – as a result – the total surface of the fat. For this reason, milk should be pasteurized before or immediately after homogenization.
- Addition of raw milk to pasteurized homogenized milk.

It is no longer believed that there are different groups or kinds of milk lipase. Differences in activity and behaviour result from the presence of co-factors and the properties of the substrate.

Proteases

Proteases are responsible for the proteolysis or breakdown of proteins; this gives rise to unpleasant flavours (e.g. bitterness) in milk and milk products. Protease is normally excreted with the milk. This milk protease is not completely destroyed at normal or slightly increased (76 to 78 °C) HTST pasteurization temperatures. Certain bacteriological proteases are even more heat resistant (Section 6.5). Many psychrotrophics produce these enzymes (see also: bacteriological lipase).

Phosphatases

Phosphatases are able to hydrolyse organic phosphates. There is an alkaline phosphatase and an acid phosphatase. The alkaline phosphatase, whose optimum pH is 9.6, is important for the dairy industry. It is destroyed at temperatures slightly higher than those required for the destruction of non-sporeforming pathogenic bacteria. Since the destruction of these bacteria is one of the major objectives of milk pasteurization, the presence of the alkaline enzyme is an indication of improper pasteurization or properly pasteurized milk being 'contaminated' with raw milk. The alkaline enzyme enables an addition of 0.1% of raw milk to properly pasteurized milk to be detected.

The natural phosphatase activity in goat's milk is rather low. This makes the test less appropriate for this type of milk.

Under certain circumstances, the enzyme reactivates after pasteurization, especially in cream that has been submitted to a moderate heat treatment, such as HTST pasteurization. Butter manufactured from such cream may show a positive phosphatase reaction. Reactivation is also possible in UHT-treated milk and milk products.

Other enzymes

Other enzymes found in milk are catalase and peroxidase which are able to decompose hydrogen peroxide respectively into water and free molecular oxygen and into water and active oxygen-ions.

2.2.9 Other components of milk

Trace components

In addition to mineral trace components, a number of organic trace components are found in milk. They are believed to be intermediate products in the synthesis of the various milk components.

Feed components may be excreted with the milk; some have an unpleasant flavour, although it is claimed that when certain plants that grow in pastures are grazed, the aroma of the milk improves.

Somatic or body cells

Body cells (leucocytes), originating from the udder, are always found in fresh milk, even if the milk is drawn from healthy quarters. The number of somatic cells may vary considerably, but it is generally lower than 100000 per ml. Counts of 500000 and more are an evidence of abnormalities, usually being an indication of mastitis. Milk from seriously diseased udders may contain millions of cells.

If the milk of a large number of animals is mixed, the infected milk of one or more animals will be diluted with milk of healthy animals and it becomes more difficult to detect abnormalities.

While the milk is in storage the cells will gradually disintegrate.

Micro-organisms

Even aseptically drawn milk may contain some bacteria. They originate from the teat channel of the udder. Milk from diseased animals may contain large numbers of bacteria.

Antibiotics

Antibiotics are used for the treatment of diseases in animals. Penicillin is generally used, especially as a therapy in mastitis, in which case it is mostly directly infused into the udder. But other antibiotics may also be used.

If an antibiotic is introduced into the udder, part of it will be absorbed by the tissues of the animal and part of it will be excreted in the milk. It will especially appear in the milk in the two milkings following the treatment. Normally, two or three days are needed for complete excretion, but even longer excretion periods are possible, mainly depending on the ointment used as a solvent for the antibiotic. Oil-based ointments may be responsible for long-lasting low-level residues in the milk. Therefore, such ointments should only be used at the very end of the lactation period.

Antibiotics may also be excreted in the milk after the animal has received intramuscular injections with an antibiotic, or even after it has consumed feeding stuffs containing antibiotics.

Penicillin may be responsible for certain allergic reactions in man. Moreover, repeated administration of even small quantities of penicillin may lead to the development of resistant strains of bacteria, and thereby threaten people's health.

Traces of antibiotics have a detrimental effect on a number of milk-processing procedures. They can inhibit lactic-acid bacteria, thereby seriously disrupting the manufacture of cheese, yogurt, sour-cream butter and other fermented products.

Antibiotics are stable in milk; they do not suffer any appreciable loss in activity through pasteurization. Active antibiotics have been found in dairy products like cheese and milk powder, and – although they follow the water-phase – also in butter.

For these reasons, milk from animals treated with antibiotics should not be supplied for human consumption and processing for as long as the milk contains these substances. Usually, a waiting-period of at least three days has to be observed if the udder has been treated and even one day more in case of an intramuscular injection.

Pesticides

Certain chemical compounds, often called pesticides, are used to control insects and plant diseases. If not applied in the proper way they may contaminate the animal, either directly through the skin or the respiratory system, or indirectly through the feed. The 'contaminated' animal excretes some of the pesticide in its milk.

Forage grown on land previously used for growing crops that need heavy treatment with pesticides, such as fruits and cotton, may be the origin of considerable quantities of pesticides in milk. It is thus bad management to graze animals in orchards that have been sprayed with pesticides, or to feed animals with grass cut in such orchards.

Since some of the pesticides are toxic to man, only the relatively non-toxic pesticides should be used in dairy husbandry, and care should be taken to eliminate the risk of contaminating milk-producing animals.

Heavy metals

Sometimes milk is seriously contaminated with heavy metals, mainly originating from milking equipment. Some of the metals, especially copper, catalyse the oxidation of milk fat.

Sanitizing agents

In proper milk-hygiene practices the use of detergents and disinfectants is indispensible. However, residues of these compounds may be found in milk.

Some of the disinfectants used in the dairy industry, the so-called chlorine compounds, are unstable in the presence of milk constituents and decompose rapidly. Their residual effect is low. Only relatively high concentrations will affect the bacteriological quality of milk, but smaller amounts may already produce noticeable off-flavours.

Other disinfectants, like quaternary ammonium compounds, are far more stable and have a higher residual effect. Their presence in milk may even involve risks of starter failures (Section 7.2) in the production of fermented milk products, butter and cheese. Moreover, the presence of such compounds in crude milk may interfere with the grading of milk by means of the methylene blue reduction and the resazurine test (Section 12.1).

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2.3 Some physical properties of milk

In addition to the physical properties of milk components, a few characteristics of milk itself that are of particular interest to the dairy industry will be discussed in this chapter.

Density

The density of a product is the weight in grams of 1 ml of that product; it is mostly determined at 20 °C. Sometimes, the concept of specific gravity is used, which indicates the ratio of the weight of a certain volume of a product to the weight of the same volume of water at a specified temperature. Unlike the density, the specific gravity is scarcely affected by the temperature.

The density of full-cream milk depends on the fat content and the solids-non-fat content (SNF); the former has a density lower than 1, whereas the latter has a density higher than 1. The density of water is practically 1. The density of milk falls if water is added, so the density is often used as a rough indication of whether milk has been adulterated with water (Section 5.2).

However, a high density cannot be considered as a criterion for the quality of milk, because it is also influenced by the composition of the milk. The density of liquid fat of cow's milk is about 0.927, that of its plasma about 1.033. This means that milk with

Table 2. Density of milks from various species.

Animal	Density
Cow	1.029
Buffalo	1.031
Goat	1.033
Sheep	1.036

a fat content of 3.00% will have a density of 1.0295 and milk with a fat content of 4.50% will have a density of 1.0277. Almost 6% of water could be added to milk with the lower fat content to bring it to the same density as the milk with the higher fat content.

Buffalo's and ewe's milk have higher fat and solids-non-fat contents than cow's and goat's milk, but since the densities of fat on the one side and solids-non-fat on the other side tend to compensate for each other, the differences between the species are hardly larger than within the species.

Bearing these considerations in mind, examples of the density of milks from various mammals are given in Table 2.

Total milk solids. The total milk-solids content of milk can be determined by drying a certain quantity of milk and weighing the dry residue. A simpler method applies a formula for the calculation of the total solids content from the fat content and the density. Various formulae are used, e.g. for cow's milk in the Netherlands:

$$TS = 1.23\ F + 2.6\ \frac{100(d - 0.9982)}{d}$$

where:

TS = total solids content of milk
F = fat content by Gerber method (capacity pipette 10.77 ml)
d = density (g/ml) at 20 °C

The solids-non-fat content is found by deducting the fat content from the total solids content.

This formula is of limited value, because it was developed for a certain kind of milk and depends on the way the fat test and the density test are performed (Section 12.1). The formula does not guarantee accurate results for kinds of milk other than cow's milk.

Freezing point

The freezing point of milk is depressed by dissolved components, principally lactose and salts. Although a number of factors, such as breed, feed, disease, etc. can affect the concentration of the various milk constituents, such differences do not or hardly affect the freezing point of the milk. Since it is one of the most constant physical characteristics of milk, the freezing point is generally used as a reliable method to detect adulteration of milk with water.

The freezing point of the milks of individual animals within one species may vary slightly, but the more milk is bulked, the more the measured freezing point will approach the average value.

The freezing points of milks from individual cows may vary from −0.53 to −0.54 °C. The freezing-point depression of buffalo's milk is of the same magnitude, but that of goat's milk is – on average – about 0.04 °C lower. Adding water (which has a freezing point of 0 °C) will raise the freezing point of milk. Therefore, depressions lower than −0.54 or −0.53 °C (i.e. freezing points higher than −0.54 °C) in cow's and buffalo's milk are generally assumed to indicate adulteration with water.

In the case of reconstituted and recombined milk, the freezing points may be higher than −0.54 °C if the legal standard for the solids-non-fat content of milk is low, because in this case the recombined or reconstituted product may contain less solids (i.e. more water) than the original milk used for the manufacture of the powder.

pH

The pH or the hydrogen ion concentration of milk indicates its real acidity. It is a far better method for recording the acidity of milk and milk products than the titratable acidity, because it is less variable, although it is influenced by the temperature. Technological processes depend on the pH of the milk rather than on the titratable acidity.

The pH of milk varies slightly between species; variations within species are sometimes greater. The pH of cow's milk normally varies between 6.6 and 6.8, that of buffalo's milk generally lies a few tenths lower, whilst goat's milk is distinctly acid, with a pH between 6.3 and 6.7. Only human milk is neutral.

At a pH of 4.6 to 4.7 lies the iso-electric point of cow's milk; this is the point at which the milk coagulates at room temperature. The higher the temperature rise, the higher the pH at which the milk will coagulate. At boiling temperature, coagulation starts even at a pH over 6.0.

Colostrum may have a slightly lower pH than normal milk, but at the end of the lactation the pH usually shows a slight increase. Mastitis milk may also have a higher pH.

Buffering capacity and titratable acidity

The buffering capacity or buffering value of milk is the resistance of milk to changes in its real acidity, that is its pH, when an acid or alkali is added.

Although fresh milk has a pH slightly below neutral, that is below 7.0, a considerable amount of sodium hydroxide must be added to neutralize milk against the indicator phenolphthalein. The quantity of a standard alkaline solution, usually $^{1}/_{9}$ N NaOH[1], which is required to neutralize milk in the presence of phenolphthalein is named the titratable acidity. At the point of neutralization, the colour of the milk changes from white to a faint pink. The quantity of $^{1}/_{9}$ N alkaline solution in millilitres required to neutralize 100 ml of milk is the titratable acidity expressed in degrees Dornic (°D) or 0.01% lactic acid (1 °D ≈ 0.01% lactic acid). The amount of indicator added to the milk affects the result of the test. Therefore, this amount should be standardized.

The initial titratable acidity of fresh milk does not result from the presence of lactic acid, but from the presence of much weaker acids, namely proteins and salts. Therefore, it is misleading to give the acidity of milk in 'per cent lactic acid'.

Estimating the titratable acidity of milks as a means to identify milk with an increased acidity, that is sour milk, may also be misleading, because a high titratable acidity may be due to the 'richness' of the milk. Milk at the end of the lactation period has a higher acidity than average.

The titratable acidity and the buffering capacity of milk vary considerably between and within species. Milk from animals within one breed with varying protein contents will show varying titratable acidities, although the pH values of such milks are the same or similar.

The acidity of fresh cow's milk varies between 13 and 15 °D, but acidities lower than 12 and higher than 16 °D are found. Although the protein content of buffalo's milk is higher, the titratable acidity is generally somewhat lower, varying between 12 and 14 °D. This is because there are fewer other alkaline-binding compounds in this milk, most probably fewer alkaline-binding salts. The titratable acidity of goat's milk is even lower than that of buffalo's milk. The buffering capacity of goat's milk is poorer than that of cow's milk.

Heat stability

Under normal conditions, milk can withstand heating without noticeable change in appearance, that is without coagulation of the proteins. The colour of intensively heated milk may darken as a result of the formation of complex protein-lactose compounds or caramelization of the lactose. Only after prolonged heating at very high temperatures is coagulation, or 'heat damage' of the casein possible, resulting in the destabilization of the casein. The lower the temperature and the shorter the time of heating required to destabilize the casein, the lower the heat stability of the system.

The heat stability of milk is mainly affected by its pH, but a number of other factors also play a role. The addition of certain chemical compounds, in most cases phosphates, may improve the stability.

Buffalo's milk causes more problems in the manufacture of concentrated products than cow's milk (Section 10.1) because its heat stability is lower. Replacing up to 20%

[1] 1/9 N NaOH = 1/9 mol/l NaOH solution (SI Unit System; Système International d'Unités).

of the calcium in milk by sodium considerably improves the heat stability in buffalo's milk.

Further reading

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See also: 'Further reading' Section 2.2.

2.4 Micro-organisms in milk

Micro-organisms are the smallest organisms having their own metabolism. They generally consist of one cell, and are believed to belong to the plant kingdom, although some investigators would prefer to classify them in the animal kingdom.

Without the activities of micro-organisms, life would be impossible. These activities are performed by enzymes produced by the organisms. If these enzymes function within the micro-organisms, they are called endo-enzymes; if they are excreted and function outside the cell, they are called ecto-enzymes. Sometimes, micro-organisms are destroyed – for instance by heat treatment – but their enzymes survive.

Micro-organisms are important for the dairy industry, either because their metabolism produces products that are undesirable and cause spoilage, or because their metabolism results in ripening or maturing processes, which are required in the production of various types of milk and dairy products.

Micro-organisms are classified according to the system of 'binary nomenclature', which allocates two Latin names to each type of micro-organism. The first name is the name of the genus (plural: genera), the second name is the name of the species. Each species may consist of a large number of strains, which show slight differences in characteristics. Such strains are indicated by numbers and letters, or by a third name, often the name of the investigator who detected the strain.

Three main groups of micro-organisms can be distinguished:
- bacteria,
- yeasts,
- moulds.

Viruses and bacteriophages do not belong to the micro-organisms, because they have no real metabolism of their own; they can only multiply in living cells.

Although many types of micro-organisms are found in milk, only a limited number is important to dairy industry. The major groups will be discussed briefly. More detailed information can be found in specialised manuals and handbooks.

2.4.1 Bacteria, yeasts and moulds

Bacteria

Bacteria are small, single-celled organisms. They multiply by partition, in which case a partition wall is formed in the mother cell and both halves grow until they separate as two new cells. The diameter or thickness of a bacterial cell is generally 0.5 to 1 μm; the length may vary from 1 to 5 μm.

Bacteria are either spherical, or rod- or spiral-shaped (Figure 5). The last-mentioned ones being of slight importance to dairy industry. The term 'coccus' is generally applied to all spherical bacteria. The group of coccus is divided into diplococci (pairs), tetracocci (fours), streptococci (chains) and staphylococci (irregular clusters). Rod-shaped bacteria differ in length and thickness. Some rods (Bacillaceae) are able to form endospores. These spores are more resistant to heat, desiccation and ultraviolet light than the vegetative mother cells. They may remain dormant for years and germinate again when conditions are favourable.

Many physiological and chemical tests are available for the identification of bacteria. A basic test used for classification is the Gram colouring method. Bacteria are classified according to whether they can be coloured with a certain dye, into Gram-positive or Gram-negative.

Classification of bacteria. There are several classification systems. Some are based on morphology and others on physiology. In this book, a system originally developed by Bergey and subsequently modified will be followed; it has been considerably simplified and restricted to the major groups important to the dairy industry. This means that

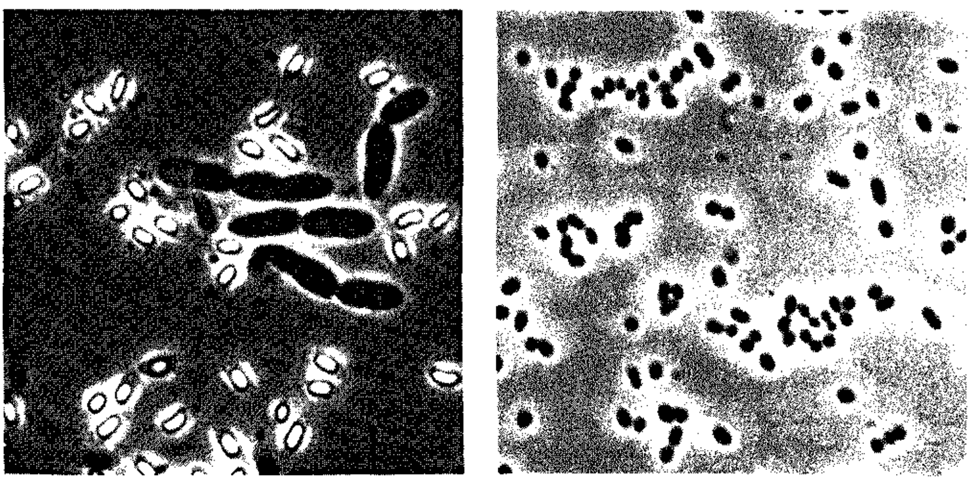

Fig. 5. Left: spore formers (*Bacillus cereus*). Right: cocci (*Micrococcus*). Photo's: Wageningen Agricultural University.

Table 3. Bacteria important for dairying. After: 'Bergey's Manual of determinative Bacteriology'.

Bergey's Manual	Family	Genus
Part 7. Gram-negative aerobic rods and cocci	I Pseudomonadaceae	*Pseudomonas*
	uncertain affilation	*Alcaligenes* *(Achromobacter)* *Acetobacter* *Brucella*
Part 8. Gram-negative facultatively anaerobic rods	I Enterobacteriaceae	*Escherichia* *Salmonella*
		Klebsiella *Enterobacter*
	II Vibrionaceae	*Aeromonas*
	uncertain affilation	*Flavobacterium* *Chromobacterium*
Part 14. Gram-positive cocci	I Micrococcaceae	*Micrococcus* *Staphylococcus*
	II Streptococcaceae	*Streptococcus* *Leuconostoc*
Part 15. Endospore-forming rods and cocci (gram-positive)	I Bacillaceae	*Bacillus* *Clostridium*
Part 16. Gram-positive non-sporeforming rod-shaped bacteria	I Lactobacillaceae	*Lactobacillus*
Part 17. Actinomycetes and related organisms (gram-positive)	Coryneform bacteria	*Corynebacterium* (human and animal parasites and pathogens) *Brevibacterium* *Microbacterium*
	I Propionibacteriaceae	*Propionibacterium*
	Order I	
	I Actinomycetaceae	*Actinomyces*
	II Mycobacteriaceae	1. *Mycobacterium*

For complete and detailed information: Bergey's Manual of determinative Bacteriology, Williams & Wilkins Comp., Baltimore.

not all the bacteria that may be found in milk and that may (under certain circumstances) be able to develop in milk and milk products, have been included.

The bacteria are classified in large groups or Parts, based on a few readily determined criteria. Most groups include a number of families and the families include genera. The major groups are shown in Table 3.

Unfortunately, the names of many genera and species have changed several times as a result of an initial misnaming or as a result of changes in the classification system, coupled with alterations of the names of bacteria. Bergey's Manual gives both old and new names.

Most bacteria important to the milk processing industry belong to Part 14 and Part 16, namely the Streptococcaceae and the Lactobacillaceae, although other Parts contain bacteria that contribute to some dairy processes, such as the *Propionibacterium,* which is important for the 'eye production' in some cheese varieties, like Emmental. Many bacteria belonging to other Parts are found in milk products, but their role is uncertain and in most cases their contribution to the production or ripening processes is dubious. Many of the bacteria in the other Parts and listed in the table are harmful to man or to the quality of the products.

In Part 7 many Gram-negative and putrefactive bacteria, originating from water and soil, are found, such as psychrotrophic *Pseudomonas* species. Psychrotrophic *Achromobacter* species are believed to belong to this group as well. These bacteria are often named 'water bacteria'. The *Brucella* species, pathogenic to man, cattle, sheep, goats and/or other mammals are classified in this part.

Part 8 contains many pathogenic bacteria, such as species of the genera *Escherichia* (mastitis in cows and enteric diseases) and *Shigella* (dysentery). *Escherichia* is found in the alimentary tract (canal) of man and warm-blooded animals. Its presence in pasteurized milk or products manufactured from pasteurized milk can be considered as an indication that the product has been contaminated from a faecal source. The genus *Staphylococcus* in Part 14 deserves special attention, because it includes many pathogens that may cause infections or produce toxins; *Staphylococcus aureus* is notorious in the dairy industry. Species of *Micrococcus* are found in dairy industry, but they are not believed to be pathogenic.

In Part 15 the spore-forming bacteria are represented. Many species of the genera *Bacillus* and *Clostridium* are found in dairy products. They are usually responsible for defects that occur under aerobic and anaerobic conditions.

In Part 17 human and animal parasites and pathogens, including species responsible for diphtheria and pseudotuberculosis belonging to the Coryneform bacteria are classified. The microbacteria that also belong to this group are fairly heat-resistant; they are chiefly found in dairy products and on dairy equipment. The bacteria that cause tuberculosis belong to the genus *Mycobacterium.*

Yeasts

Yeasts too are generally unicellular, but they are much larger than bacteria (5-10 μm).

They multiply by budding: one or more buds grow on the mother cell until they 'wall off'. Other yeasts multiply by producing two, four or eight spores within one cell. Reproduction by the formation of a partition wall is also possible (Figure 6, left).

Yeasts are aerobic and are able to grow at high acidities. Although some species are characteristic to a few fermented milks, their contribution to dairy industry is very limited. In general, they are contaminants and may develop in fermented milk products like butter, in condensed milk and on the surface of some cheeses. Spoilage by yeasts results in gas formation and the production of gassy and fruity flavours.

Moulds

Moulds are even larger than yeasts (Figure 6, right). They form a tangle of fine threads named mycelium. The different species may have different colours, from white to dark green or blue. The threads of hyphae consist of one or more cells with a thickness of a few micrometers. Parts of the threads of some varieties may develop into new mycelia. Moulds are strictly aerobic and prefer an acid environment. In the dairy industry they make an essential contribution to the production of a variety of cheeses, but they can cause spoilage in other areas. In a humid atmosphere they may develop on ceilings and walls and on other surfaces in milk processing areas.

Moulds multiply by forming spores, which are produced in sporangia, as in the genus *Mucor*, or at the end of mycelium threads, as in the genera *Penicillium* and *Aspergillus*.

Compared with the vegetative mother cells, the spores of yeasts and moulds are only a little more resistant, if at all, to increased temperatures, desiccation and UV radiation. Unlike the Bacillaceae they will not survive normal pasteurization procedures.

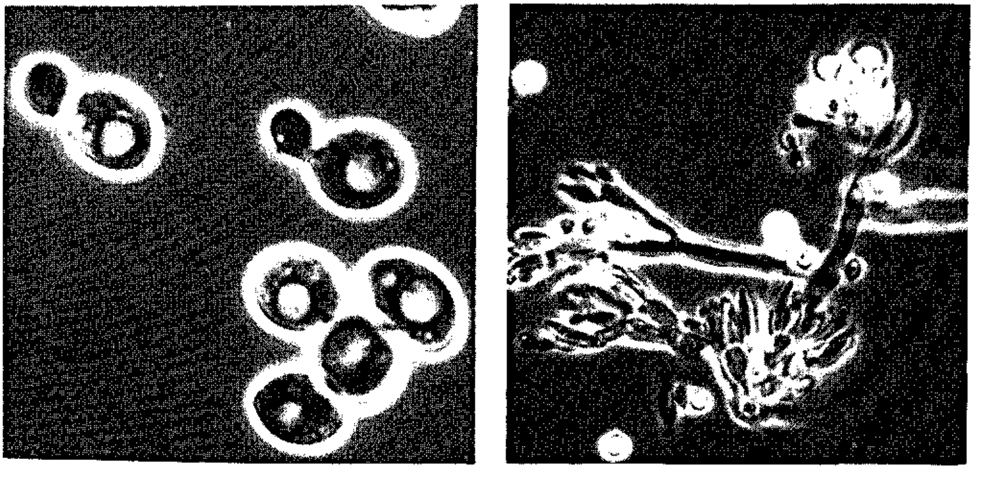

Fig. 6. Left: yeasts. Right: moulds (*Aspergillus*). Photo's: Wageningen Agricultural University.

2.4.2 Living conditions of micro-organisms

Micro-organisms can only develop under the right conditions. Factors of influence are:
- availability of water,
- availability of nutrients,
- presence or absence of molecular oxygen,
- acidity,
- temperature,
- growth-inhibiting agents,
- UV-radiation.

Water

Water is the major component of the cells, and considerable quantities are required for reproduction, that is for the production of new cells. Moreover, the organisms absorb all nutrients in the form of a solution, and all biological processes take place in a solution.

Dried products, such as milk powder, are protected from bacteriological deterioration, because they lack water. The drying process itself does not destroy all micro-organisms; furthermore, many survive long storage periods in the dry product. The bacterial count of milk powder immediately after drying decreases only slowly, and it may take years before the product becomes more or less sterile. High storage temperatures will promote the destruction of bacteria.

In addition to the water content of the product, the osmotic pressure of the water-phase is important. Solutions with a high percentage of dissolved compounds will have a high osmotic pressure. In such solutions, water will be removed from micro-organisms that have a lower osmotic pressure in their cells; this prevents them from metabolizing and from reproducing. Sensitivity to osmotic pressure varies between different types of organisms. Some bacteria stop reproduction in solutions containing 15% salt, but the growth of other species is already inhibited in a solution containing only 2% salt.

The sugar in sweetened condensed milk (two parts of sugar are added to one part of water) results in an osmotic pressure high enough to prevent micro-organisms from developing.

Nutrients

Nutrients are required for the development of micro-organisms, because they supply the 'building materials' for the new cells. Furthermore, the breakdown of complex compounds into simpler compounds delivers the energy required for the cells to function. The breaking down of compounds in combination with the production of other compounds is named fermentation.

Milk is rich in nutrients, and as such is an excellent nutrient for many micro-organisms, but since the requirements of the various organisms vary, not all will find all the nutrients they need in milk. Thus, not all organisms will be able to grow in milk. However, compounds produced by the metabolism of certain organisms may serve as a nutrient to other organisms. In this way, a chain of microbiological processes may ultimately completely break down the various organic compounds in milk.

Symbiosis is a phenomenon whereby certain micro-organisms create an environment that facilitates the development of other organisms, for instance by the production of certain nutrients or by bringing about a favourable acidity. The reverse phenomenon, in which case the development of certain organisms inhibits the development of others, is named antagonism.

Oxygen demand

As regards the demand for molecular oxygen, it is possible to distinguish three categories of micro-organisms:

– Aerobic organisms, to which most yeasts, all moulds and a large number of bacteria belong. They require free molecular oxygen for their development.

– Anaerobic organisms, most bacteria. They flourish in the absence of oxygen.

– Facultative aerobic or anaerobic organisms. These organisms grow aerobically as well as anaerobically, although often exhibiting a preference for one of the two conditions. A typical example of this group are the ordinary lactic acid bacteria, which will develop more quickly at the bottom of a can or bottle than at the top. As a result, the milk at the bottom of such containers starts to acidify first. Sometimes, the top layer of the milk seems sufficiently 'fresh', whilst the milk at the bottom is already sour.

Acidity

A suitable acidity is very important for a proper development of micro-organisms. In this respect, the pH is decisive and not the titratable acidity. At the normal pH of milk, many organisms are able to develop, but some, like moulds and yeasts, prefer a more acid environment, whereas others, like most of the protein-fermenting bacteria, stop reproduction at increased acidity. Therefore, the acid produced by lactic acid bacteria will prevent the development of certain putrefying bacteria and actually preserves the milk, although it becomes sour.

But lactic acid bacteria themselves can also only tolerate a certain acidity, although not all are equally sensitive. This means that during the process of acidification of milk, various species of lactic acid bacteria may succeed each other. Normally, acid production stops at a pH of 4.2. Some investigators believe that not only the pH, but also the lactic acid itself retards further development of these bacteria.

Temperature

Three temperatures are important for the development of micro-organisms: minimum

temperature, optimum temperature and maximum temperature.
The various types of micro-organism show a wide variation in their sensitivity to temperatures. Broadly speaking, bacteria are able to develop between 0 and 70 °C. Most yeasts and moulds grow best between 20 and 40 °C.

The minimum temperature is the temperature below which no reproduction is possible, because metabolism stops. There are enormous differences between the various species of micro-organisms; some will grow at temperatures close to and in exceptional cases even a few degrees Celsius below freezing point, whereas others need considerably higher temperatures. In general, the 'shelf-life' of milk and milk products is considerably improved by cooling the products below 10 °C, but in general, temperatures as low as 3 or 4 °C are required to stop all activities almost completely. Holding milk at low temperatures will not destroy micro-organisms. Freezing may lead to a slow destruction because cell walls are ruptured by ice crystals.

The maximum temperature is the temperature above which the micro-organisms will cease to develop.

The optimum temperature is the temperature at which micro-organisms develop best. According to their optimum temperature, micro-organisms are classified into the following categories.

Psychrophilic	– Bacteria with an optimum temperature of about 4-6 °C; growth range 0-20 °C
Psychrotrophic	– Bacteria which are able to grow below 10 °C; they generally belong to the group of mesophilic bacteria
Mesophilic	– Bacteria with an optimum temperature of about 25-35 °C; growth range 10-45 °C
Thermophilic	– Bacteria with an average optimum temperature of about 50 °C; growth range 30-80 °C
Thermoduric	– Bacteria which survive normal pasteurization temperatures (e.g. 30 min at 63 °C or 15 sec at 72 °C)

Psychrophilic micro-organisms. These are the cold-loving organisms. In general they are able to grow between 0 and 20 °C; their average optimum temperature is about 4 to 6 °C. There is often confusion in literature between this group of organisms and the group named psychrotrophics. The latter – in general bacteria from various genera – are able to develop at very low temperatures, that is below 7 °C, although their optimum temperature is much higher. They are frequently found in raw milk, and usually originate from contaminated water as their main source. For this reason they are sometimes called water bacteria. In many cases, the adulteration of milk with water actually means an inoculation of the milk with this kind of bacteria. Psychrotrophics are also found in dust from barns and feed and from other sources. If unpasteurized milk is stored for long periods on the farm or at the milk plant, it may be spoiled by psychrotrophics. Changes in milk handling systems during recent decades, resulting in much longer storage of milk at very low temperatures have stimulated the occurrence of psychrotrophic bacteria (see also Section 3.4).

Most of the psychrotrophic bacteria are actually mesophilic, having their optimum temperature in the same range as the normal mesophilic bacteria. They differ from the latter by being able to grow, be it very slowly, at the very low temperatures. They are destroyed under normal conditions of pasteurization, but they may be found in pasteurized milk, as a result of recontamination. Many representatives belong to the genera *Pseudomonas, Flavobacter, Alcaligenes* and *Achromobacter.* Many of them produce extremely heat-resistant lipolytic and proteolytic enzymes which may cause spoilage in refrigerated pasteurized and even in UHT-sterilized milk (Section 6.5). They produce only little or no acid, but they are able to develop an unpleasant rancid, bitter or fruity taste, which has earned them the name 'spoilage bacteria'. Off-flavours in pasteurized milk, which are often believed to be absorbed from other beverages or food stored together with the milk in household refrigerators, may actually be produced by psychrotrophics.

Mesophilic micro-organisms. Mesophilic micro-organisms prefer moderate temperatures for their development. They generally grow at temperatures between 10 and 45 °C, with an optimal average of about 25 to 35 °C. Many of the useful bacteria in dairy processing belong to this category. Moulds and yeasts are generally mesophilic.

Thermophilic micro-organisms. Thermophilic micro-organisms prefer temperatures between 30 and about 60 °C, with an optimal average of about 50 °C. Raw milk on the farm may be contaminated with thermophilics from soil, hay or other dry and 'dusty' feeds. Milk solids that accumulate in improperly sanitized milking utensils are also a common source of contamination. Enormous populations of thermophilics may build up in dairy plants if milk is kept at high temperatures over long periods, or in dairy equipment that is used continuously for extended periods and not sanitized properly. It is well known that thermophilics develop in balance tanks, where warm milk, cream or condensed milk is stored, and that they also grow in pasteurizers.

Sometimes, thermotolerant or thermoduric bacteria are mistaken for thermophilic bacteria. The former are able to grow at high temperatures, although their optimum temperature is much lower than that of the true thermophilics. There are two types of thermotolerant bacteria:

– Vegetative thermotolerants which can stand high temperatures in their vegetative form (that is, without heat-resistant spores), but which are normally destroyed at temperatures below 100 °C. This group includes some mesophilics, like microbacteria and micrococci.

– The spore-forming bacteria. The vegetative form of these bacteria will be destroyed at pasteurization temperatures (i.e. below 100 °C), but they are able to produce spores, which require much higher temperatures to be destroyed. Very intensive heat-treatment procedures have to be applied; for instance, sterilization temperatures of 120 to 130 °C for 10 min or longer. All bacteria of the family Bacillaceae belong to this category.

Unlike moulds and most yeasts, bacteria never produce more than one spore per vegetative cell.

Milk preservation by cooling and heating. Cooling milk to sufficiently low temperatures and keeping the milk at such temperatures will prevent or at least retard the development and metabolism of micro-organisms, depending on their 'cold-sensitivity'.

Heat treatment of milk for a certain period will destroy micro-organisms, provided a sufficiently high temperature can be applied during a sufficiently long period. The time-temperature relationship is decisive for the rate of destruction (Section 6.1). Below a certain temperature, which depends on the characteristics of genera and species, no heat destruction will take place, not even with prolonged periods of heating.

Growth-inhibiting agents

The development of micro-organisms in milk will be retarded by certain growth-inhibiting agents, such as detergents left behind in the milking utensils after sanitization, antibiotics secreted with the milk by animals treated with antibiotics, and deliberately added preservatives.

Milk also possesses natural inhibiting properties, as a result of the presence of so-called bacteriostatic compounds, which are excreted with the milk. These compounds are more active in milk kept at room temperature than in cooled milk. However, their activity lasts longer at the lower temperatures. The bacteriostatic substances are thermolabile; they are inactivated at certain minimum temperature-time combinations. The main substances are:

- the agglutinins, belonging to the group of immunoglobulins (Section 2.2); they are inactivated at a minimum time-temperature combination of 20 seconds at 76 °C;
- the lactoperoxidase system (Section 3.5), which is inactivated at a minimum time-temperature combination of 20 seconds at 86 °C.

To preserve the bacteriostatic properties as much as possible in pasteurized milk, it may be found useful to apply an HTST heat treatment at the lowest possible temperature.

The difference in the keeping quality of milk from various mammals is often attributed to differences in bacteriostatic properties.

UV radiation

Micro-organisms are sensitive to sunlight. Under tropical conditions and especially in the dry season, UV sunrays have a sterilizing effect on the ambient atmosphere, whilst the high temperatures have a drying effect on the milking utensils. This improves conditions for hygienic milk production and handling.

2.4.3 Reproduction of micro-organisms

The growth of micro-organisms in numbers is usually named reproduction. Microbes are considered to be destroyed or dead if they have lost the ability to reproduce. If the living conditions are unfavourable, micro-organisms cease reproducing, but as soon as these conditions improve, reproduction starts again. Freeze-dried starters and cultures are an excellent example of micro-organisms in a state of inactivity or rest. In general, such a state weakens the organisms and, if it lasts long enough, they may die.

Growth of micro-organisms

The rate of growth of micro-organisms under favourable conditions can be represented by an exponential growth curve (Figure 7). In such a curve the logarithms of the numbers of organisms per unit volume are plotted against the time of incubation. During the first period the organisms will show hardly any or only a minimal development (period A to B); this period is referred to as the lag phase. Thereafter, a rapid development or reproduction takes place, which can be represented by a straight line: the so-called exponential phase, often called 'logarithmic phase', (period C to D). At the end of this period of massive growth, the increase in numbers slows down, because the nutrients required for development of the organisms become scarce and/or the concentration of the fermentation products reaches a point where development of the organisms is inhibited. At a certain moment, the number of organisms reaches its maximum and remains constant for a certain period of time (period E to F), the stationary phase. Thereafter, a decline in numbers can be observed.

Under different environmental conditions the growth curves of the same strain of an organism will not be identical.

To improve the keeping quality of milk and milk products, it is important to prolong the lag phase as much as possible by controlling all factors influencing it. The main factors are:

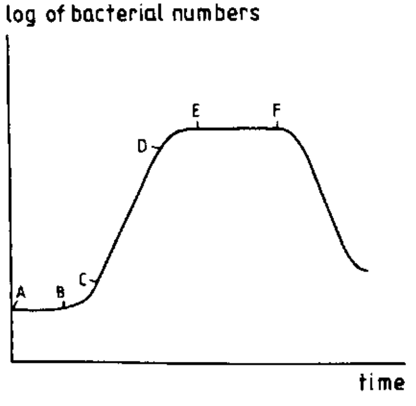

Fig. 7. Exponential growth curve.

– The presence of bacteriostatic substances and antibiotics producing micro-organisms.
– The activity of the organisms. The weaker these are, the more time they require to come to full development. Organisms left behind on properly sanitized and dried dairy utensils will show a longer lag phase than those on poorly cleaned and wet utensils, where they can continue to develop.
– The environmental conditions. Under optimal living conditions the lag phase will be shortest.
– The type of organism. Different organisms have lag phases of different durations.

Generation time
The concept 'generation time' was introduced to indicate the rate of growth of micro-organisms, that is the time a certain species or strain requires to double its number during the exponential phase of the growth curve. The generation time of a certain species or strain depends on its environmental conditions. In Table 4, a theoretical example is given of the development (under the same conditions) of the numbers of bacteria having generation times of 20 and 60 minutes, respectively.

Rate of destruction of micro-organisms
The numbers of micro-organisms will be reduced if the milk is heated, provided the temperature of heating exceeds the lethal or destruction temperature. But not all are killed at the same time. If the logarithms of the numbers of heat-surviving organisms

Table 4. Theoretical example of the development of bacteria with generation times of 20 and 60 minutes.

Time after the logarithmic phase of massive reproduction started (min)	Number of bacteria	
	species with a generation time of 20 min	species with a generation time of 60 min
0 min	1	1
20 min	2	
40 min	4	
60 min	8	2
1h 20 min	16	
1h 40 min	32	
2h	64	4
3h	512	8
4h	4096	16
5h	32768	32
6h	262144	64
7h	2000000	128
8h	16000000	256

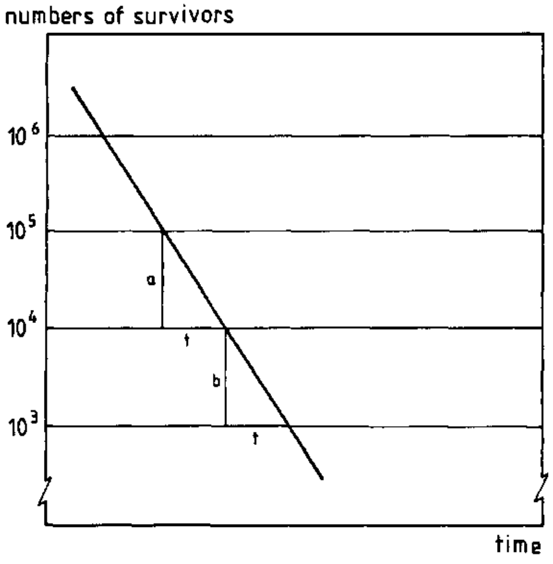

Fig. 8. Bacterial heat-destruction curve.

are plotted against the time of heating, a straight line will be obtained (Figure 8). This actually means that if, at a certain temperature, 50% of the microbes are destroyed during the first minute, during the second minute 50% of the remaining bacteria will be destroyed, and so on. The exponential survival curve is a phenomenon similar to the exponential phase in the growth curve. It can only be a straight line if one species or strain is considered, and it refers only to vegetative cells of bacteria, and cells and spores of yeasts and moulds. The figure shows that the time required to bring the number of bacteria down from 100000 to 10000 (a) is exactly the same as the time required to bring the number down from 10000 to 1000 (b). In the figure, this is represented by the distance t, which is thus the time required to reduce the number of bacteria by 90%.

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2.5 Milk products and human health

From a nutritional point of view, milk can contribute considerably to human health. On the other hand, it can be a dangerous vehicle for a great variety of milk-borne diseases, which easily spread over large groups of the population, assuming an epidemic character if no proper precautions are taken.

Although milk may be contaminated with certain chemical compounds which can be hazardous to human health, milk-borne diseases are generally considered to be caused by pathogenic micro-organisms or viruses (pathogens for short), either directly or indirectly. Micro-organisms can be pathogenic to man, because they are able to affect human health either directly by their activities in the human body, or indirectly by producing toxins or other harmful compounds in milk and milk products before these are consumed by man. Several diseases of man can be spread if milk has been contaminated either directly by human beings or indirectly by infected utensils, equipment, water, etc. Moreover, a number of animal diseases may be transmitted to man if milk produced by diseased animals is consumed.

Contamination of milk and milk products can take place at any stage along the marketing chain between animal and consumer. But with modern production and processing techniques, and adequate health inspection and quality control, it is possible to provide consumers with safe and healthy milk and milk products. However, where proper control is lacking, and especially if non-pasteurized milk and milk products are consumed, there is always a risk of an outbreak of a milk-borne disease. Raw milk and pasteurized milk sold in open containers, should always be boiled before consumption, as should packaged pasteurized milk of doubtful quality.

The principal pathogens found in milk are shown in Table 5 and are briefly discussed.

Man is susceptible to bovine tuberculosis. Animals suffering from this disease may contaminate their milk. There is little or no proof that human tuberculosis is spread through milk. Tuberculosis is very rare in goat's milk. This does not mean that goat's milk is safe to drink without proper heat treatment, because in many tropical countries brucellosis is fairly common in this milk.

Not only goats, but also cattle, buffaloes and sheep may suffer from brucellosis. Although man can be infected by direct contact, most cases are caused by drinking raw milk. The illness is also known as contagious abortion, Bang's disease and, in man,

Table 5. Diseases in man caused by micro-organisms and viruses.

Direct		Indirect
animal source	human source	
bovine tuberculosis	human tuberculosis	mastitis
brucellosis	diphtheria	*Staphylococcus aureus*
foot-and-mouth disease	scarlet fever	*Bacillus cereus*
anthrax	dysentry	*Clostridium perfrigens*
Escherichia coli	*Salmonella*-typhoid	
Campylobacter jejuni		
Q-fever		
Salmonella-typhoid?		

as Malta, Mediterranean or undulant fever.

Cloven-hooved animals are very susceptible to foot-and-mouth disease. Man is rarely affected.

All warm-blooded animals, including man, are susceptible to anthrax. *Bacillus anthracis,* which causes this disease, produces spores that are excreted with the milk. The bacillus is only found in the milk shortly before the animal dies. Therefore, consumption of contaminated milk is unlikely. The spores are very persistent. It is very unlikely that milk from herds in which the disease has broken out will be offered for consumption.

Cattle and other cloven-hooved mammals, and man are susceptible to *Rickettsia* (or *Coxiella*) *burnetti*, which causes the disease Q-fever. This pathogen belongs to the most heat-resistant pathogens and in the event of outbreaks of the disease it is often recommended to increase the HTST pasteurization temperature by a few °C.

Escherichia coli bacteria which cause intestinal disorders, may make milk a dangerous food if unboiled, especially for babies and infants. The bacteria can multiply in milk under conditions of storage at tropical temperatures. The presence of non-pathogenic coli bacteria in milk and milk products is also undesirable, because it indicates that a recontamination after heat treatment has taken place. This includes a risk of a contamination with pathogenic bacteria, especially because coli bacteria are always present in the intestinal tract.

The importance of *Campylobacter jejuni* (which causes symptoms rather similar to cholera) for the dairy industry is not yet completely understood. After milk has been contaminated, the viable numbers of this bacterium rapidly decrease.

The contamination of milk with *Shigella dysenteriae,* which causes dysentery, and by *Salmonella* species, which cause various disorders, including typhoid and paratyphoid fever, often takes place by polluted water, but man can also be the source of the infection. Human carriers need not themselves exhibit symptoms of disease.

Although mastitis is a serious threat to the animal industry, the most common infectious organisms are considered to be non-pathogenic to man. However, some of these organisms, for instance, certain strains of *Staphylococcus*, produce a toxin that can cause acute and serious gastroenteritis in man.

Putrefactive bacteria like *Bacillus cereus* and *Bacillus subtilus* break down proteins in milk, thus forming compounds that are believed to cause intestinal disorders. It is not very likely that milk with such compounds will be consumed, because it has a very unpleasant taste.

Clostridium perfrigens produces pathogenic toxins in the human body after consumption of milk containing this spore-forming bacterium.

Remark: The topics raised in this section will be discussed in greater detail in the companion volume 'Strategy for dairy development in the tropics and subtropics'.

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2.6 Nutritive value of milk and milk products

For the newly-born infant or animal, milk is an almost complete and well-balanced food. Its main constituents, which supply energy and building materials for the young, are accompanied by various nutrients, like minerals, vitamins and other organic compounds important from a nutritional point of view. Since all nutrients in milk are present either in the form of a solution, a dispersion or a colloidal system, the 'mixture' is easily digestible. However, milk is comparatively low in iron and vitamin D, and the young aminal must depend on the iron reserves in its liver and the formation of vitamin D in the body by the action of the sun on its skin.

Mother's milk can only serve as the sole food for the young individual for a limited period, because of the young animal's increasing requirements and the decreasing quantity of milk produced by the mother. Mother's milk is difficult to replace, therefore, the decision to replace it by other products should not be taken too lightly.

For children and adolescents, milk is an excellent supplement to their daily diet, especially if this diet shows little variation and is poor in nutrients necessary for development. Too often, the diet of children is too one-sided, and although the growing child may eat a reasonable quantity or even its maximum ingestible quantity of bulk food, the quality may not be sufficient to satisfy all its needs. For similar reasons, milk should be taken by pregnant women and young mothers, especially during their period of nursing.

Adults require certain minimum supplies of energy, proteins and other nutrients. These may be obtained from foods other than milk and milk products, but these foods must provide a complete diet in sufficient quantities. This is often not the case. Under such circumstances, milk can form a highly nutritional supplement, which compensates for many shortcomings in the other foods.

Unfortunately, many inhabitants of developing countries are too poor to buy the comparatively expensive milk and milk products, and yet it is especially this group of potential consumers who suffer from one-sided diets, and to whom milk would be a welcome addition.

2.6.1 Milk proteins

Proteins, or rather their amino acids, are the building blocks of the body of the growing creature, and if they are not available or available in insufficient amounts, the physical development of the creature will suffer. Many experts fear that long-lasting shortages of adequate nutrition with proteins will result in a sub-optimal mental development of children. Amino acids are also required for the maintenance of body tissues and for a large number of metabolic functions.

Humans are able to break the proteins down and to transfer the amino acids so obtained into other amino acids they require. However, 8 amino acids, the 'essential amino acids', cannot be produced by the human body in this way and these must be consumed with the food. Growing children even require two additional 'essential amino acids', because they cannot produce these two quickly enough to meet their demand. Milk proteins are built of 20 different amino acids and contain all the amino acids the human body requires.

The value of a protein depends on its digestibility and the relative proportions of the various amino acids in the protein. Each of the essential amino acids should be available in a minimum amount. This means that the amino acid with the comparatively greatest deficit will be the 'most limiting amino acid'. It determines the biological value of the protein, that is the actual value of the protein for supplying the required amino acids: the greater the deficit of the 'most limiting amino acid', the lower the biological value of the protein. The biological value of milk and egg protein is very high; it approaches 100%.

Casein and whey proteins contain a surplus of the essential amino acid lysine. This amino acid is short in most vegetable proteins, such as cereal protein. The total biological value of the proteins in staple vegetable foods can be considerably improved by the addition of milk proteins, either by the consumption of milk and milk products, or by the incorporation of such products into the basic foods, for instance by adding milk powder to bread and similar products.

Normal processing procedures hardly affect the nutritional value of milk proteins.

2.6.2 Milk fat

Milk fat is an easily digestible nutritious fat, and the most important energy supplier in milk. Although they contain proteins and other important nutrients, skimmed milk products are inadequate suppliers of energy. Moreover, they lack the fat-soluble vitamins (Section 2.2), unless these vitamins have been artificially reintroduced.

Unfortunately, milk fat has been suspected of being injurious to health. Particular attention has been given to its cholesterol content and its low content of polyunsaturated fatty acids. It has been assumed that the consumption of milk fat will increase the cholesterol content of the blood, and hence the incidence of arteriosclerosis and thus increase the probability of cardiovascular diseases (e.g. heart attack). Since cholesterol is synthesized in the human body in amounts far in excess of the normal intake through milk fat, the latter cannot be considered the major cause of arteriosclerosis, if at all. Actually, the intake of milk and most milk products, except butter, appears to lower the blood cholesterol content. Moreover, it is scientifically not correct to centre attention on a 'doubtful' role of milk fat, or even on dietary factors at large, while ignoring or underestimating all other factors that may play a part in the occurrence of cardiovascular diseases.

The heat treatment of milk and other processes applied in the manufacture of various milk products does not affect the natural quality of the fat.

2.6.3 Lactose

Lactose is an important supplier of energy in the diet, but apart from its direct nutritional value, it is also believed to assist in the absorption of calcium and magnesium by the human body. Some investigators believe that it suppresses the development of putrefying micro-organisms in the intestine, by producing a mildly acid environment.

Lactose is a disaccharide and cannot be absorbed in the intestine as such. It must first be broken down into two simple monosaccharides: glucose and galactose. Human babies and infants, like all young mammals, secrete a special enzyme, lactase, for this purpose. But in large groups of the population in different parts of the world, the production of lactase may lessen, or stop (almost) completely after weaning. This phenomenon is especially found amongst non-white populations, although it is very unlikely that it has anything to do with skin colour. As a result of a reduced lactase activity in the intestine, more lactose will pass into the large intestine, where the flora present convert it principally into lactic acid and gases, which can cause cramps, diarrhoea and similar symptoms.

The phenomenon of lactase deficiency, or lactose intolerance has led to much confusion, especially because 'lactose intolerance' was mistaken for 'milk intolerance'. The results obtained with standard lactose intolerance tests, usually administering a watery solution of 50 g lactose to adults and 1 to 2 g per kg live weight to children, give no or insufficient information about the existence of milk intolerance, because the amounts of lactose used in these tests are much higher than the amounts of intake

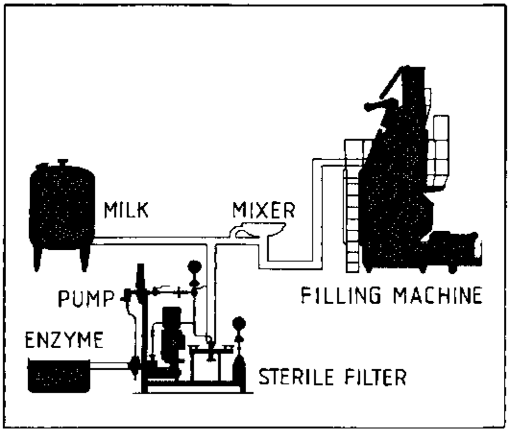

Fig. 9. Tetra Lacta system for UHT milk. The enzyme lactase is administered to the milk before the aseptic filling machine. The manufacturers claim that with 10 mg enzyme per litre of milk, almost complete hydrolization of lactose is achieved by storing for 10 days at 25 °C. Courtesy: Tetra Pack International AB.

under normal conditions of milk consumption. Moreover, since lactase deficiency is seldom absolute and milk intake is generally distributed throughout the day, milk tolerance is much higher than the lactose-tolerance tests predict, and 250 ml or a few glasses of milk a day will easily be tolerated by most consumers. For persons suffering from real milk intolerance as a result of lactase deficiency, milk products with hydrolysed lactose may be produced by treating the milk with the enzyme lactase (Figure 9).

Products like mature cheese and ghee do not contain lactose, but fermented milk products like yogurt and buttermilk still do, because the lactic acid bacteria ferment only part of the milk sugar (15 to 40% at the most). Consequently, these products cause fewer problems than milk. The same applies to fresh cheeses, with incomplete lactose fermentation. See also: Bulgarian milk (Section 7.3).

2.6.4 Minerals

Milk contains large amounts of easily digestible calcium and phosphorus, both of which play an important role in building up the skeleton and teeth of the growing individual. It is difficult to provide the human being, especially infants, children and expectant and nursing mothers, with sufficient quantities of calcium if no milk or milk products are consumed. Deficiencies of calcium generally lead to rickets in children. Adults require the element for the maintenance of the skeleton.

As well as supplying calcium and phosphorus, milk is also an excellent source of a large number of trace elements, which are either important as building materials of the body, or are essential components in enzymatic and other reactions.

2.6.5 Vitamins

Apart from the milk components discussed, milk contains a number of other components that are important nutritionally. The vitamins in milk deserve special attention. The most important ones will be discussed briefly.

Vitamin A or retinol

Vitamin A is a fat-soluble vitamin. Apart from the vitamin itself, provitamin A or carotenoids contribute to the vitamin A activity of milk. These carotenoids are responsible for the yellow colour of milk fat. Since neither ruminants nor non-ruminants are able to produce carotenoids, they depend totally on their intake of feed for their provitamins. The carotenoids of the feed are converted into vitamin A in the intestinal wall of the animal, and hence pass to the udder.

Deficiencies of this vitamin result in cessation of growth, defects in the teeth and diseases of the eye which may lead to complete blindness.

Normal processing techniques in the dairy industry have little effect on the vitamin A content of milk and milk products. Prolonged heating at high temperatures, such as occurs in some sterilization processes, and in ghee making may result in losses of 20% and higher.

Vitamin D or calciferol

Vitamin D is a fat-soluble vitamin. The vitamin D activity resides in a number of structurally similar compounds, of which vitamin D_2 and vitamin D_3 are the principal forms; both are found in milk. Vitamin D_2 or ergocalciferol is the vegetable form, produced in plants by solar irradiation acting on its provitamin ergosterol. It finds its way into the milk through the body of the animal that eats the plants. Vitamin D_3 or cholecalciferol is produced by solar radiation on its provitamin 7-dehydrocholesterol in the skin of man and animals. It is then transmitted to the mammary gland.

The natural vitamin D content of milk largely depends on the food eaten and the amount of sunlight to which the animal is exposed. The vitamin D content of domestic milk is often too low to meet the optimal requirements of children still mainly depending on milk as their major food. For this reason, milk is sometimes enriched with vitamin D_2 or D_3.

Deficiency in vitamin D results in a decreased rate of growth and a reduced deposit of calcium and phosphorus in the skeleton, leading to rickets in children. Older people suffering from a low calcium intake combined with vitamin D deficiency are more susceptible to fractures of bones, which are difficult to cure.

Vitamin D is very stable in milk and is hardly if ever affected by normal processing.

Vitamin B

Vitamin B consists of a group of different water-soluble vitamins that have little relation in function or structure. The vitamins of this group are synthesized by microorganisms in the rumen of ruminants, which do not need a supply in their feed. The levels of these vitamins in the milk of ruminants are fairly constant. Man and non-ruminants depend on the intake with their food. With the exception of children still depending on milk as their only or most important food, milk cannot be considered as an important source of the vitamin B group, although it is important as a source of riboflavin in the diet.

Vitamin B_{12} or thiamin. Vitamin B_1 or thiamin is found in the serum of milk. Deficiencies lead to disturbances in the metabolism of carbohydrates, resulting in symptoms of diseases (e.g. related to the central nervous system). Vitamin B_1 can be destroyed by heat, but normal pasteurization procedures have little influence. It shows good resistance against oxidation.

Vitamin B_2 or riboflavin. Vitamin B_2 or riboflavin is a water-soluble pigment giving whey a greenish-yellow colour. It is involved in enzymatic oxidation of various organic compounds in metabolic processes. The major symptoms of deficiency are lesions of the skin, the eye and mucous membranes. The vitamin is reasonably stable to heat and oxidation, but is gradually destroyed by exposure to light.

Other B vitamins. Some of the other vitamins belonging to this group are:
– Nicotinic acid or niacin (anti-pellagra vitamin) which controls oxidative reactions. This vitamin shows good resistance to heat treatment, oxidation and light.
– Vitamin B_6, which plays an important role in amino-acid metabolism. Normal pasteurization procedures hardly affect the vitamin. Sterilization of milk and exposure to light may result in a considerable loss. It is reasonably resistant to oxidation.
– Panthotenic acid, which is essential in a number of metabolic processes. It shows good resistance to high temperatures, light and oxidation.
– Folic acid plays a role in the growth of man; it is essential for the development of the red blood cells. It shows good resistance against heat treatment.
– Vitamin B_{12} or cyanocobalamin controls a number of vital functions, of which the production of red pigment in blood cells seems to be the most important. It is reasonably stable to heat, but may be inactivated by other products formed in milk.

Vitamin C

The water-soluble vitamin C or ascorbic acid (anti-scurvy vitamin) plays an important role in metabolic processes in general and in the formation and maintenance of intercellular material in the body of man and animals in particular. Ruminants are able to synthesize it themselves, but man and other animals depend completely on the vitamin C content of their food. Regular supplies are necessary, because sufficient amounts of this vitamin cannot be stored in the body.

The typical symptoms of vitamin C deficiency are general tiredness and decreased resistance to infections. More serious symptoms are haemorrhages in various tissues.

Vitamin C is easily oxidized, particularly in the presence of copper. The first oxidation product, dehydroascorbic acid, has the same biological value as ascorbic acid. Further oxidation inactivates the product biologically. Heat treatment as such hardly affects the vitamin, provided no oxygen (air) is available. Normal pasteurization procedures and UHT treatment restrict losses to less than 10%. Losses during sterilization are much higher.

2.6.6 Comparison between human milk and the milk of mammals

Apart from differences in the composition of milk between species, wide variations are found within the species, breeds and also between individuals. Such differences mainly result from genetic characteristics, but they also depend on environmental factors.

As mentioned already, mother's milk is indispensible for the young human being, although the human body is a poor synthesizer of vitamins and the vitamin content of milk fluctuates with the food the mother consumes.

Milk from our domestic animals has certain shortcomings as a substitute for mother's milk, because of the differences in composition and the chemical properties of its constituents. These shortcomings are serious, especially for very young and prematurely born babies. This has led to milk from domestic animals being modified with the view of obtaining a product more similar to human milk, so-called 'humanized milk'. The modifications include increasing the lactose content, substantially reducing the protein (especially casein) content, lowering the salt content, and adding some polyunsaturated fat and vitamin D.

Remark: A more thorough treatment of these subjects and a discussion of the nutritional value of various milk products, of food aid and related matters will be found in the companion volume 'Strategy for dairy development in the tropics and subtropics'.

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3 Milk handling on the farm

3.1 Preventing milk from being contaminated with micro-organisms

As long as the milk is still in the udder of a healthy animal the bacterial count will be low, usually lower than 500 per ml. The flora will mainly consist of slowly-reproducing non-pathogenic micrococci. High bacterial counts are found in cases where the udder is inflamed. After the milk leaves the udder, contamination will take place during milking, milk handling, transport and storage and the micro-organisms will begin to grow rapidly after they have passed the lag phase (Section 2.4). Initially high bacterial counts and rapid growth of micro-organisms will badly affect the keeping quality of the raw milk and the quality of the products manufactured from such milk. Milk contaminated with pathogenic bacteria may be harmful to human health. Therefore, all possible measures should be taken to limit the contamination of milk and to prevent further bacterial growth.

Milk may be contaminated with micro-organisms originating from:
- the skin of the animal,
- the milker's hands,
- the air,
- the milking utensils.

Contamination from the skin of the animal
Dirt, such as dung, soil, bedding, feed, dust, etc. may fall into the milk from the animal's body during milking. During this period the milk is also exposed to the risk of contamination with bacteria present in the intestinal tract of the animal, such as coliforms and pathogens. Milking in the rain may badly affect the quality of the milk if the rainwater is allowed to flow from the animal's body into the milk.

To prevent dirt falling into the milk, the coats of the milking animals should be kept clean. They may require regular brushing, especially if the animals are kept in the shed or under conditions of zero grazing (restricted area). Adhesion of dirt can be limited by clipping the flanks and the udder, whenever appropriate.

The main source of infection is the udder. Dirt, such as dung, and hairs and scales of the skin may easily drop into the milk as a result of the motion of the udder during milking. Therefore, before milking, the udder should be rubbed with a dry, clean cloth to remove all kinds of dirt. This also stimulates milk let-down. To prevent diseases being transmitted from one animal to the other, proper precautions have to be taken, e.g. by using a fresh cloth for each animal. Paper towels – if available – are very useful for this purpose, but may be expensive.

If the udder cannot be cleaned sufficiently in this way, the udder and the teats may have to be washed. This should be done using fresh clean water, either from a fine spray directly connected to the water-pipe, or from a bucket. In the latter case it is advisable to use two buckets if the udders are very dirty. The water from the first bucket is used to give the udder a pre-rinse and to remove the visible dirt. The water from the second bucket is used for the final washing. After washing, the udder should be dried in such a way that no liquid can drip into the milk, because this could result in severe contamination of the milk.

It is often recommended to disinfect the udder with a solution containing up to 400 ppm active chlorine, but such high concentrations of chlorine should be avoided, because they will irritate the skin of the udder. Therefore, the chlorine content should always be lower than 50 ppm.

It will be clear that clipping and certain of the other measures for hygienic milk production discussed in this paragraph cannot be applied to all types of mammals.

Contamination from the milker

The danger of contaminating milk by the hands of the milker is often underestimated. The risk is not so much because dirt may fall from his hands into the pail, as because the milker's hands may be a source of pathogenic bacteria of human origin. Moreover, a disease can easily be carried from one animal to another on the milker's hands.

Before milking, the milker should wash his hands. He must repeat this every time there is a risk that his hands are contaminated. It is advisable to use disinfectants, but disinfectants used to wash the hands and the udder should not have a strong odour.

Milking with wet hands is not acceptable, because liquid from the hands can wash dirt and bacteria from the animal into the milk. Note that a towel frequently used for drying the hands may act as a conveyor of micro-organisms, especially if it becomes wet, because it may then be a source of rapidly multiplying bacteria.

The clothes of the milker should be clean, as must be the milking-stool and the cord that is used to tie the animal or its legs. If these precautions are not observed, the milker may contaminate his hands every time he touches stool and cord.

Contamination from the air

Airborne contaminations are not the most serious ones; their importance is often overestimated. Nevertheless, at milking time everything causing dust should be avoided, especially if the animals are milked in the shed. Dust from animal feed may carry micro-organisms into the milk. Some of the organisms spread by the air can cause defects in milk products. The shed should not be cleaned out shortly before or during milking, because of the risk of airborne contamination. For the same reason, the animals should not be fed shortly before or during milking. If this is not possible, for economic or practical reasons, care should be taken not to raise too much dust.

Care should also be taken with the feeding of silage, because this is the most serious carrier of *Clostridium* bacteria, which are responsible for defects in many varieties of cheese. Moreover, the – sometimes unpleasant – odours of the silage may be absorbed by the milk, either directly, or indirectly through the body of the animal. For this reason, silage should not be present in the shed during milking, and should not be fed to the animals less than 8 hours before milking.

Contamination from the milking utensils
The contamination of milk by the animal and the milker are, like airborne contamination, especially important for reasons of hygiene. From a technological point of view, however, the potential for milk to be contaminated by contact with unclean milking utensils, such as strainers, pails, cans, milking machines, etc. is far more important. Inadequately sanitized utensils are the most potent sources of micro-organisms, because most of these micro-organisms are specific milk-bacteria, in other words, bacteria that find their optimum living conditions in milk. These bacteria remain after improper sanitization of the equipment. They can be in a very virulent stage and grow profusely in traces of milk that are left in utensils. Such remnants are especially found in cracks and pits, but will also occur on the surface of utensils, especially if these are rough, (e.g. because of rust). Detergents and disinfectants will not easily penetrate into such places during the rather short period of sanitization, and milk residues quickly inactivate disinfectants. As soon as the fresh milk comes into contact with the utensils, these virulent micro-organisms will contaminate it. Conditions are favourable for their rapid reproduction. These organisms include thermoduric and thermotolerant species, as well as many mesophilic producers of lactic acid. Improperly cleaned milking utensils are the major source of thermoduric bacteria.

To avoid contamination, seamless, smooth-surfaced utensils should be used. Pottery, wooden pails and rusty equipment are not fit for the hygienic handling of milk. Under primitive conditions of milk handling, porous vats, (made of pottery), are often used to store and ferment milk. In this case, the milk is 'naturally inoculated' by the fermenting bacteria left behind in the pores, but at the same time, undesirable organisms can get into the milk.

In the case of machine milking, contamination originating from the body of the animal, or from the air can be minimized. But great care must be taken to sanitize milking machines and – in the event of pipeline milking – the pipelines, the measuring vats, etc. Outbreaks of thermoduric infections in pasteurized milk as a result of the introduction of machine milking are not exceptional. The condition of the rubber parts of the equipment is especially critical. Worn out and cracked parts must be replaced, even if they are still functional.

3.2 Quality of raw milk

High-quality raw milk should have a normal appearance, flavour and taste; moreover, it should have a low bacterial count and must not contain extraneous matter. The milk from different species looks and tastes different. The word 'normal' should therefore be seen within the context of a specific species.

3.2.1 Appearance of milk

Normal milk has an opalescent white to yellowish colour. The opalescent character is the result of light being dispersed by the protein particles and the fat globules of the milk. Milk with comparatively small fat globules will disperse more light and give the product a 'whiter' appearance. This is also the case with homogenized milk (Section 5.3). The yellow colour of milk is predominantly the result of the presence of carotenoids in the milk fat. The intensity of the colour mainly depends on:

– Fat content of the milk. Skimmed milk has a blueish-white colour, owing to the casein particles in the fat-free product; whey has a greenish colour, related to the riboflavin.

– Feed. Feedstuffs with a high carotene content, such as most green fodders and silages, will lead to milk with a more pronounced yellow colour than feeds with a low carotene content, such as straw, hay and turnips.

– Species of animal. The colour of milk of buffaloes, goats and sheep is white as a result of the absence of carotenoids. Considerable differences are found between breeds of cow. The milk fat of Jersey cows is much darker yellow than that of Holstein cows.

At the beginning of the lactation, animals may produce slightly reddish colostrum or milk, because of the presence of blood. Milk may also contain blood as a result of abnormalities, such as injuries of the udder or mastitis. Such milk is not fit for human consumption, and neither is milk that shows other abnormalities on physical examination, e.g. lumps and clots. In most cases, mastitis is responsible for these defects. The best procedure is to examine the milk before the actual milking starts, by drawing some of it in a strip-cup. It is bad practice to pour out or to draw milk onto the floor, because it will putrefy and attract flies and may transmit mastitis to other animals.

A high dirt content may also affect the colour of milk.

3.2.2 Taste and flavour of raw milk

Taste of raw milk

Normal fresh milk has a bland, slightly sweet taste. There are differences in sweetness between the milks of various species of mammals, because of differences in lactose content. The salts of milk also contribute to the taste of milk. At the end of the lactation, the milk may acquire a slightly salty taste because of the increased salt content. The same holds true for mastitis milk.

Absorbed flavours in raw milk

In addition to flavours and odours produced by micro-organisms and enzymes, milk may contain undesirable flavours and odours originating from various sources, either excreted with or absorbed by the milk.

Most of the off-flavours occurring in raw milk will be transferred to the processed products, but some may disappear during heat treatment. Most flavours and odours are mainly absorbed by the milk fat, others are absorbed by the aqueous phase. It is sometimes claimed that the latter are easier to remove by de-aeration or vacuum treatment (Section 6.5) than the former.

Since milk easily absorbs flavours, it should be stored and transported in a clean, odourless atmosphere. Even if the milk is packed in materials that seem to be impermeable to external flavours, caution should be observed.

The principal flavours absorbed by milk are: feed flavours, unclean flavours, and pharmaceutical and chemical flavours.

Feed flavours. The flavour of silage is easily absorbed by milk, either directly (via the air) or indirectly via the animal (Section 3.1). Other feed flavours, like those related to turnips, onions, certain weeds, etc., are only absorbed via the body of the animal.

Unclean flavours. Unclean odours and flavours can often be related to unclean sheds and body odours of the animal. If animals are milked in the shed, the milk should be removed immediately after milking. It should be stored in an odour- and dust-free, cool place, well away from products with a strong flavour. The milk container should be covered, to protect the milk against flies and other insects, and against dust. It is best to use a special milkroom.

Goat's milk may have a very strong and unpleasant flavour, which is also often found in white cheese, cream, butter and other products manufactured from such milk. It will not disappear during heat treatment. The fat of strongly flavoured goat's milk has a comparatively high acidity. There are several reasons for the existence of the flavour:

- it originates from certain compounds in the animal's feed;
- the fat of goat's milk is rich in caproic, caprylic and capric acids. Fat hydrolysis releases these fatty acids, which are responsible for the flavour;
- capric and caproic acids are secreted by the skin glands of the buck. The acids contaminate the milk of the goat if she comes into contact with the buck.

Boiling the milk immediately after milking, and separating the bucks from the goats may help to minimize the risk of these off-flavours occurring in the milk.

Pharmaceutical and chemical flavours. These flavours may originate from medicine used to treat the animals, and also from detergents and disinfectants used to sanitize equipment.

3.2.3 Cleanliness of milk

Milk must be clean; it may not contain extraneous matter, either dissolved, or undissolved. The presence of too much extraneous matter in milk indicates unhygienic and careless milking and handling of milk.

Most of the visible dirt can be removed by filtering or straining. But this does not actually improve the quality of the milk; it is merely an aesthetic improvement. Since bacteria can pass through the filter, the bacteriological quality of the milk will not improve. It may even worsen, because dirt collected on the filter from a previous amount of milk will be 'washed out' by the following amount, thus dispersing the bacteria through the milk. This can be partly avoided by replacing the filter regularly.

A metal strainer with a filter pad is preferable to a simple piece of cloth. If the latter is used, it must be properly washed and dried before it is used again. Between uses it is advisable to keep it in boiling water, or to use a sterilisant. Never wring out the cloth over the milk after filtering.

In the event of machine milking, little or no extraneous matter should be found in the milk, provided the udder has been washed satisfactorily. Nevertheless, a filter may be placed in the pipeline.

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See also 'Further reading' Section 3.3.

3.3 Keeping quality of milk

Even under very hygienic conditions of milk production some contamination of the milk is unavoidable, but in general, relatively few micro-organisms will be present in the milk immediately after milking. During handling, storage and transport the number may increase considerably, depending on the type of bacteria, their virulence and the surrounding conditions, especially the temperature. Since milk is a very good substrate for the development of a wide variety of organisms, adequate measures should be taken to retard their development.

If the milk has not been properly cooled shortly after milking, a large variety of micro-organisms will start to reproduce. Lactic-acid bacteria generally overgrow the other bacteria quickly. Because of their acid production the milk will curdle. The main source of these lactic-acid producing bacteria is improperly sanitized equipment.

Surprisingly, raw milk, especially buffalo's milk, stored under tropical conditions (at relatively high temperatures) may show a better keeping quality than milk stored in areas with a more temperate climate at lower ambient temperatures. Despite poor conditions of production and handling, and transportation over long distances without cooling, the milk may reach the dairy plant without an appreciable increase in acidity. Many explanations have been given for this phenomenon. It is often believed that such 'strong' milk has better and longer-lasting bacteriostatic properties, but it is doubtful whether this explanation is correct. Some experts associate the higher buffering capacity of buffalo's milk with the longer period required to make the milk curdle (Section 2.3).

Another theory is that the ambient flora in 'strong milk' contains very few lactic-acid bacteria, but large numbers of Gram-negative rods, the so-called water bacteria (Sections 2.4 and 6.5). These bacteria may be responsible for high bacterial counts in raw milk without bringing about the visible spoilage caused by acid production. Nevertheless, the growth of such bacteria should not only be avoided for reasons of general hygiene, but also because this group includes many putrefying bacteria, deleterious to the quality of milk and possibly to the health of the consumer (Section 2.5). During the initial period of storage, the Gram-negative bacteria may consume the oxygen in the milk, thus creating an atmosphere favourable for the development of anaerobic bacteria, which may also be responsible for undesirable changes in the milk. Generally, lactic-acid bacteria will ultimately overgrow the water bacteria, but if this does not happen, the putrefying bacteria cause a bitter taste to develop and may even produce sweet curds.

Ropy milk

Milk may acquire a rope-like texture. The viscosity of such milk is high and threads of slime can be drawn from it. This milk has no particular off-flavour, provided it has not undergone other changes at the same time.

Ropiness may be caused by a large variety of 'gum-producing bacteria' which originate from contaminated water, dirt, dust, feed and similar sources. Hygienic production and handling of milk, and proper sanitization of equipment will in most cases prevent this defect. It is often very difficult to rectify ropiness, because all equipment, the barn and dairy, etc. are usually infected.

The bacteria that produce ropiness in crude milk are non-sporeforming and not thermoduric. They are killed during normal pasteurization. Therefore, the defect is unknown in pasteurized milk, provided no recontamination occurs.

3.4 Cooling of milk

Under conditions of low ambient temperatures, e.g. at high altitudes in the tropics and subtropics, milk of good hygienic quality may be kept in the shade and without refrigeration for periods of 12 hours and longer, without any noticeable organoleptic changes. But the higher the ambient temperature, the quicker the milk will spoil. Table 6 gives data on the influence of the temperature on the bacteriological keeping quality of milk. It is merely an indication, because the development of micro-

Table 6. Effect of the temperature at which *milk is held on bacterial growth and keeping* quality of raw milk.

Milk temperature (°C)	Plate count per ml after 24 h
5	3.1×10^3
10	1.2×10^4
15	1.8×10^5
20	4.5×10^5
30	1.4×10^9

After: Davis, J.G., 1965. A dictionary of dairying. Leonard Hill, London.

organisms during the storage of milk does not depend solely on the temperature, as was discussed earlier. It has been assumed that the initial quality of this milk is very good. Micro-organisms develop faster in severely contaminated milk than in milk with a low bacterial count. This may be because in the severely contaminated milk the bacteriostatic properties are overshadowed, or because there is some kind of symbiosis.

The data in Table 6 show that at temperatures above 10 °C the increase becomes important. Under tropical conditions, where the milk may have a temperature around 30 °C and higher, the increase is disastrous. The table also shows that at 10 °C the increase in bacterial count is four times as fast as at 4 °C. Under conditions of poor hygiene, plate counts of 500000 are no exception, and with plate counts that are four times as high (2000000), biological changes of fat protein and sugar become noticeable; this is why hygienic milk production and deep cooling of milk are necessary.

It is difficult to stipulate the precise temperature to which the milk must be cooled, because this not only depends on the bacterial count that is considered to be acceptable, but also on many other factors, such as:
- the species and strains of contaminating organisms;
- the time during which the milk has to be stored before processing.

Cooling to temperatures below 10 to 15 °C will usually be sufficient if the production of acid has to be prevented for short periods (e.g. 12 to 24 hours). Much lower temperatures (4 °C and lower) are required to minimize bacterial growth. Note, that as a result of changes in methods of handling of milk at the farm level and in collection centres with cooling facilities (that is a change from short periods of milk storage at comparably high temperatures to long periods at very low temperatures), the predominant micro-flora has changed from mesophilic to psychrotrophic. The latter include many of the Gram-negative water bacteria mentioned in Sections 2.4 and 6.5. If bacterial development is to be successfully retarded, milk should be cooled to temperatures below 4 °C if the milk is picked up every other day. If milk is picked up daily or twice a day and processed immediately after reception, higher temperatures are usually acceptable, but the acceptable temperature depends on the ambient conditions and hygienic quality of the milk.

Sufficient quantities of milk must be available to make it economically viable to cool milk to low temperatures by refrigeration on the farm. When small amounts of milk are produced, the cooling of milk should be centralized in collection centres. To control undesirable bacterial development and to maintain high bacteriological standards, the milk should be cooled as quickly as possible after milking, preferably within two hours. This is especially important under tropical conditions. Quick cooling stops the development of micro-organisms at an early stage in the lag-phase of the growth curve (Section 2.4). If the development is stopped at a later stage, the milk may apparently be of acceptable quality, but its keeping quality will be short; especially if the temperature rises again. Apart from retarding the growth of micro-organisms, quick cooling also extends the period that the bacteriostatic properties of the milk remain active.

Unfortunately, in many developing countries it is difficult to implement a requirement to cool milk within two hours after milking, especially because the milk is often produced in small amounts and the producers are scattered over large areas, which makes milk collection time-consuming. Sometimes, only the milk from one milking daily is supplied to the dairy plant. In this case, the morning milk is collected, so that the lower ambient temperatures can be exploited.

Some farmers who sell milk directly to the consumer, boil the milk at the farm and cool it as best they can.

Some investigators suggest increasing the temperature of the milk to about 55 °C during collection and handling at the collection centres, instead of cooling it, because most of the micro-organisms do not develop and some are even inactivated at the elevated temperature, although thermophilics and thermotolerants may grow. The system has two important disadvantages, namely:

- the organoleptic quality of the milk will suffer considerably at the high temperature;
- the collection – transportation – processing system will allow the thermophilic and thermotolerant flora to multiply.

3.4.1 Systems of cooling

Any cooling is better than no cooling if the milk has to be stored on the farm for longer periods. However, if cooling facilities are poor and the time required to take the milk to the collection centre or dairy plant comparatively short, it is not advisable to delay milk collection or milk delivery with the objective of cooling the milk first.

In all systems of cooling, the heat of the milk is transferred to a cooling agent through a separation wall. The cooling agent or refrigerant absorbs the heat of the milk. The final temperature of the milk depends on the design of the equipment. Some systems cool milk to a temperature only a few degrees higher than that of the cooling agent. The rate of cooling depends, amongst other factors, on the difference in temperature between milk and cooling agent, the surface area, the thickness and the material of the separation wall, and the movement of the liquids along the wall. Large differences in temperature promote the rate of cooling, as does the smoothness of the surface of the wall. High speed and turbulent motion of the liquids along the wall will improve the rate of heat transfer.

Several systems are available for cooling milk. The simplest systems use water from the mains or a well. If abundant quantities of well-water are available, the milk cans can be immersed in the well. This method is not advisable if the well-water is also used for drinking, because the immersion of cans easily leads to contamination of the well. Simple systems of cooling that use water will bring the milk to a temperature only 3 to 5 °C above that of the water. This means that water at a temperature of 11 to 12 °C is able to cool milk to about 15 °C at the lowest. Apart from the fact that this temperature is still high, water of 11 to 12 °C will generally not be available under warm tropical conditions, and artificial cooling, i.e. refrigeration with some kind of cold-producing equipment, will be necessary.

Ice-cones

If small amounts of milk have to be picked up and transported over long distances and it is not technically or economically feasible to cool the milk in advance, metal ice-cones may be used. These cones are inserted into the milk cans, so that the rim of the cone rests on the collar of the can and fits sufficiently tightly to prevent milk splashing out during handling and transport. The cone takes up about one-third of the volume of the can (Figure 10). If the cones are filled with crushed ice, the milk can be cooled from 30 °C to 5-10 °C during transport. The cones and the ice can be taken to the farms or the collection centres by the milk pick-up truck. The ice should be transported in an insulated box. The cones must be properly sanitized after they have been used; preferably at the chilling centre or the dairy plant.

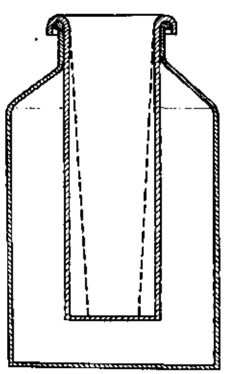

Fig. 10. Ice-cone.

Water tanks

The simplest system of cooling involves using an open tank with cold water. The cans are inserted into the tank, where they are immersed in the water up to their necks (Figure 11). The water must be refreshed continuously or at regular intervals. To allow for de-aeration of the milk during cooling, the lids of the cans should be loosened. The tank may be covered with a lid to protect the milk against flies and dust.

If well-water or water from the mains is used, this system only allows for slow cooling to comparatively high temperatures. Better results are obtained by using ice-water. To limit losses of cold by radiation, the tank and its cover must be insulated. The cooling rate can be improved by forced circulation of the ice-water in the tank.

Cooling rings

Whenever running water is available, milk can be cooled by putting a perforated tubular ring around the neck of the can of warm milk. After the ring has been connected to the mains, water will spray onto the can and flow over its surface (Figure 12). If ice-water from a cold water tank is used, the water should be collected under the can (e.g. by standing the can on a rack over the cold water tank) and recirculated.

Immersion coolers

Immersion coolers (Figure 13) consist of a system of bent tubes, which is immersed in the warm milk. The cooling agent circulates through the tubes, thus cooling the milk. Indirect as well as direct cooling can be applied (Section 4.4). In some systems, the immersed tubes rotate in the milk. The rotation may be effected by the force of the water or by other means.

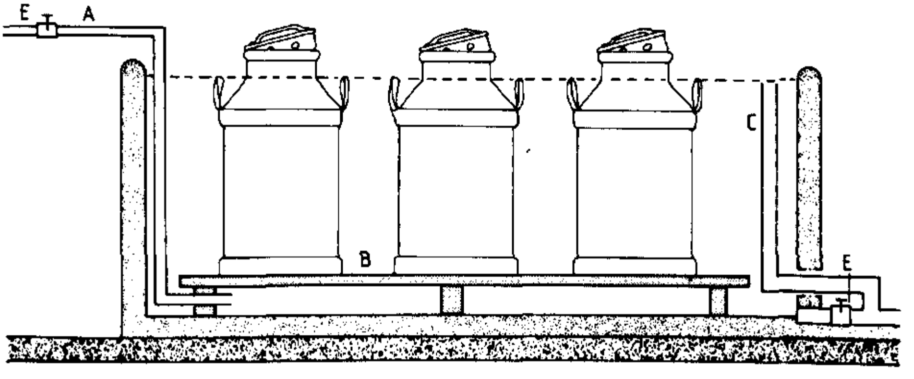

Fig. 11. Cooling tank for milk cans. A. Supply-pipe cooling-water. B. Platform. C. Discharge cooling-water. E. Valve.

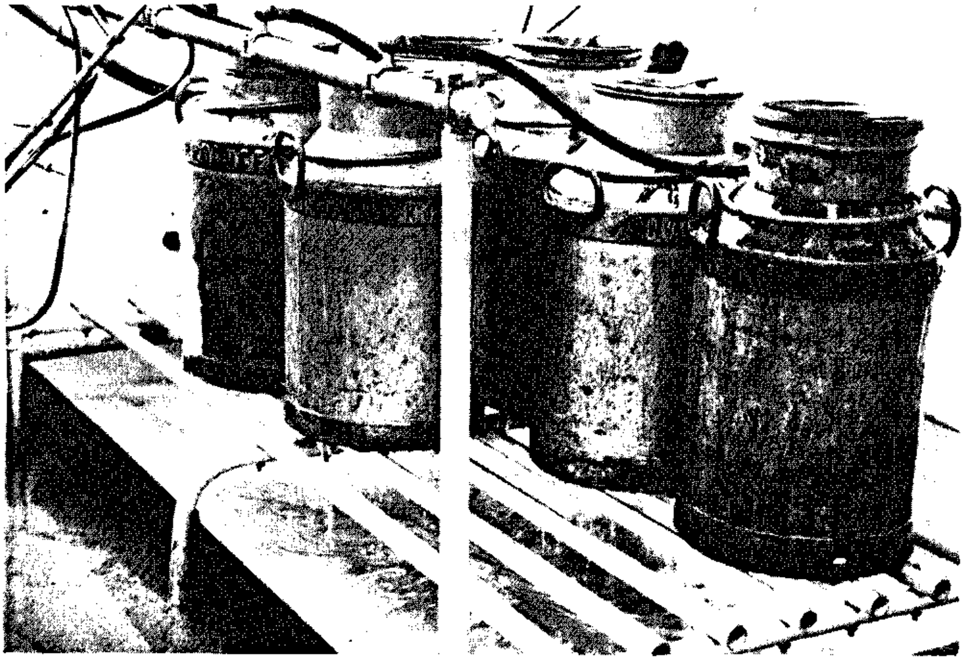

Fig. 12. Milk cans with cooling rings. Photo: A.H. Wesselingh.

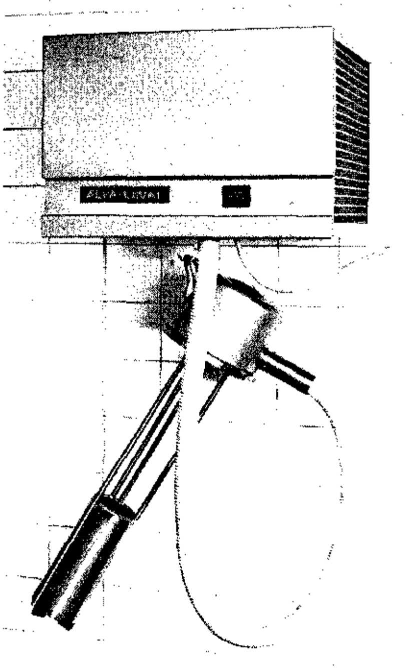

Fig. 13. Immersion cooler. Courtesy: Alfa-Laval Agri International AB.

Surface coolers

Surface coolers consist of a series of small-diameter, horizontally arranged tubes. The tubes, which are mounted on top of each other, terminate at each end in a header. The headers connect the tubes, thus allowing the cooling agent to circulate through them. The warm milk is distributed over the surface of the cooler, i.e. over the set of horizontal tubes, by means of a spreader-pipe or a tray with small openings fitted on top of the upper tube. The small openings in the spreader-pipe or in the tray allow for an even distribution of the milk over the tubes (Figure 14). The milk flows over the surface of the cooler by gravity and is collected in a tray from which it flows into a milk can or other receptacle from which it can be pumped away.

Direct as well as indirect cooling is possible (Section 4.4).

The surface cooler may also consist of two corrugated plates, welded together. The cooling agent circulates through the horizontal channels between the plates to the headers.

Surface coolers may consist of two independent sections on top of each other. The upper section is cooled with water from the mains or from a well, whilst ice-water or direct cooling is applied in the lower section.

The surface-cooling system, also called open-cooling system, is simple, but requires a proper sanitization programme. Special care must be taken to prevent airborne contaminations.

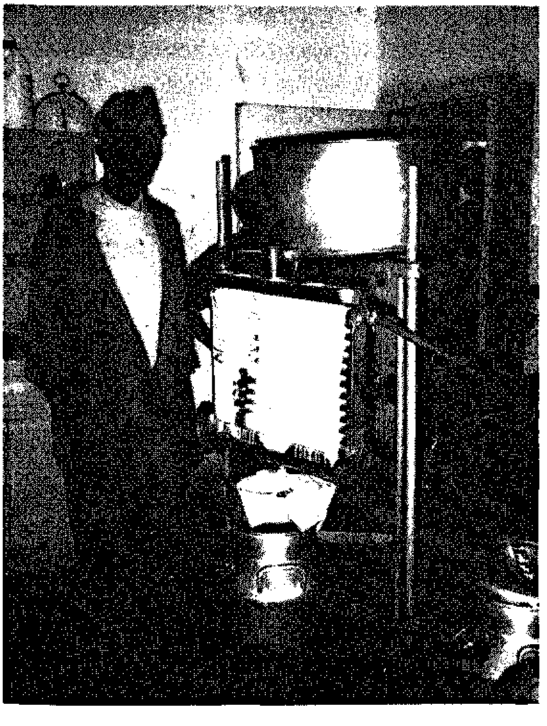

Fig. 14. Surface cooler. Photo: M.A. Luijkx.

Farm-tank coolers

Farm-tank coolers are meant for bulk-milk cooling and storage. They are either vertical, cylindrical tanks, (generally the lower-capacity ones) or horizontal, semi-cylindrical, or rectangular tanks (generally the larger-capacity ones) (Figure 15). Some of the horizontal tanks are completely cylindrical. The tanks are covered with one or two lids, which are removable or can be swung back. Many of the horizontal tanks are completely closed but have manhole covers. Tank coolers have a double-jacketed wall. The milk comes into contact with the inner wall, which is either directly or indirectly cooled by a cooling agent (Section 4.4). In the event of indirect cooling, the agent circulates in the double jacket, or is sprayed against the inner wall of the tank. The outer wall of the tank, and in most cases also the cover, is insulated to prevent cold losses by radiation.

There are several designs of farm-tank coolers. Here, only a few systems will be discussed. Systems for indirect cooling may be equipped with a separate ice-water tank, or the jacket itself may function as an ice-water tank. In this case, the pipes on which the ice bank is built may be situated at the bottom of the jacket, or between the inner and outer walls of the jacket. In the direct system, the evaporating refrigerant comes into direct contact with the inner wall of the tank.

Farm-tank coolers are equipped with one or more agitators to increase the rate of cooling. They are also intended to prevent the milk from creaming and if a cream layer has formed, to mix it again with the milk.

If the milk is distributed over a surface cooler before it enters the farm tank, the rate of cooling will be accelerated, although the importance of this should not be overestimated. The surface cooler can be connected with the ice-water tank of the farm tank.

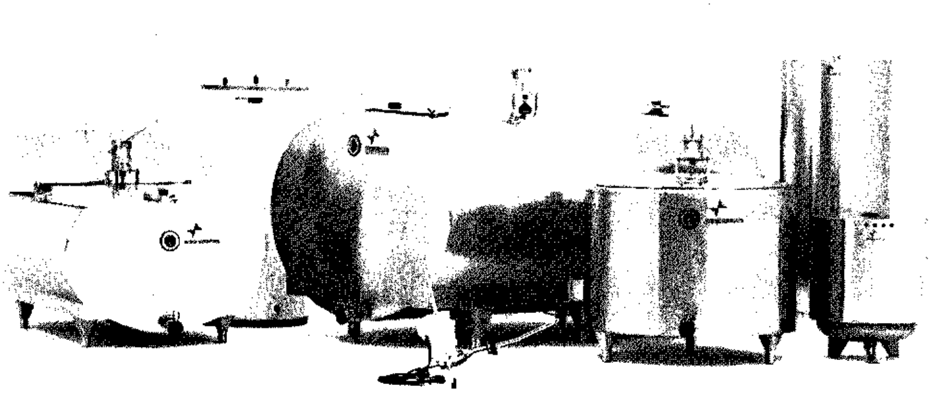

Fig. 15. Farm-tank coolers. Courtesy: Mueller Europa B.V.

Tubular and plate heat exchangers

These types of coolers are very similar to the heat exchangers (Section 6.2) in dairy plants. Both the direct and indirect system of cooling are applicable.

3.4.2 Application of the various systems

All systems of cooling can be used on farms as well as at collection centres. The choice of equipment will mainly depend on the maximum milk production on the farm or the maximum milk intake of the centre.

For small-scale operations, the available quantities of milk are usually too small for bulk cooling systems. The milk is cooled in the cans, in which case water tanks, cooling rings and immersion coolers are appropriate cooling aids. These systems are mainly found on small and medium-sized farms. At a daily production of 500 litres or more, bulk cooling systems become advantageous.

The choice between applying systems with milk cans and systems with farm-tank coolers does not depend exclusively on the quantity of milk that must be handled. It also depends on the collection system. It may not be worthwhile to set up a bulk-milk collection system if the majority of the milk producers supply small quantities of milk in cans and only a few farmers produce quantities that justify the use of farm-tank coolers. On the other hand, if large-scale producers predominate in an area, it may be worthwhile setting up a bulk-collection system and accepting and financially supporting a few comparatively small-capacity farm-tank coolers for farmers with low production, or installing a shared farm tank for a number of small suppliers. Although the small-capacity tanks may prove to be uneconomical, the system as a whole may prove to have economical and technological advantages over a system solely using milk cans, or a system with some cans and some farm tanks.

As a compromise between cans and farm tanks, high-capacity cans with contents up to 200 l can be used. Milk in these cans can be cooled with immersion coolers, whilst the cans can be lifted onto a truck or can be emptied by pumping the milk into a road tanker.

Tubular or plate heat exchangers are only appropriate if considerable quantities of milk are available; for instance 10000 litres of milk, or more. This is generally only the case in medium or large collection centres.

Surface coolers can be used for any size of operation, but they are of special interest for small or medium-sized operations.

After cooling, a rise in temperature should be prevented. The temperature of milk stored in bulk (farm-tank coolers and ordinary storage tanks) can be controlled by proper insulation and thermostatic control systems, i.e. the cooling system switches on automatically if the temperature of the milk rises. The temperature of milk in cans that have been inserted in cold-water tanks can be controlled by controlling the temperature of the water, using thermostates as explained before. Milk in cans cooled with an immersion cooler can be controlled by inserting such a cooler into the milk at the moment the temperature rises too much, or by permanently having coolers with a thermostate in the cans.

Otherwise, milk in cans that has been cooled by one way or another is difficult to keep cool, especially if the ambient temperature is high. Insulated domes can be put over the cans, to limit cold losses. Milk in cans should be picked up as quickly as possible after cooling, unless the cans can be stored in properly insulated localities, or even in cold store. Sometimes, warm milk is put directly in cold store, although the rate of cooling is slow, even if there is forced air circulation in the store.

3.4.3 Capacity of the cooling equipment

Milk should be cooled as quickly as possible after production, either at the farm or at the collection centre. The cooling capacity should be large enough to avoid any delay in cooling. Surface, tubular and plate heat exchangers allow for an almost instantaneous cooling at the moment the milk is available. The cooling rate of the other systems is lower, but considerable differences can be observed. For farm-tank coolers the standard of the International Dairy Federation could be followed:

– 'Every-day tanks' (the milk is picked up every day): in an ambient temperature of 32 °C, when the tank contains 50% of the rated volume of milk at 4 °C, and when the remaining 50% of milk is added as one batch at 35 °C, all milk shall be cooled to 4 °C in 3 hours.

– 'Alternate-day tanks' (the milk is picked up every other day): in an ambient temperature of 32 °C, when the tank contains 75% of the rated volume of milk at 4 °C and when the remaining 25% of milk is added as one batch at 35 °C, all milk shall be cooled to 4 °C in 3 hours.

The milk storage capacity on the farm or at the collection centre depends on the daily milk production or the daily milk intake respectively, and the frequency of the milk pick-up. Assuming that milk is supplied to the centre twice a day, and that there is not much difference between morning and evening production or supply, the capacity of an 'every-day tank' at the farm should be at least equal to twice the morning supply in the flush season. An 'alternate-day tank' should have a capacity at least four times the morning supply. Similarly, the capacity of the collection centre should be two to four times as much as one morning intake, depending on the pick-up programme of the dairy plant. To be on the safe side, (the milk pick-up truck may not arrive on time) it is best to aim at capacities of three to five times the morning supply.

If there is a large difference between the production of milk in the flush season and the lean season it may be advisable to use two coolers of 'half capacity' instead of one cooler of 'full capacity'.

Collection centres may act as a balancing unit for the dairy plant, i.e. allow the supply of milk to the plant to be regulated – especially on public holidays. However, under tropical conditions (and depending on the quality of the milk) it is not advisable to store the milk for periods longer than 48 hours. This time-limit includes the time during which the milk is stored at the plant before processing.

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3.5 Alternative systems of milk preservation

Preservatives for milk

Under certain conditions, it is unpractical or too expensive to cool or refrigerate milk to prevent it from spoiling: for instance, if quantities of milk are too small for the application of expensive cooling systems, or no energy is available to operate such systems. Under such conditions, preservatives that are harmless to human health may be used as an alternative. Preservatives are illegal in a number of countries. In other countries it is believed that they should be used in cases of emergency, rather than let the milk spoil, but that they should never be regarded as a substitute for hygienic milk handling.

Hydrogen peroxide. Hydrogen peroxide is a preservative that has been known and used for a long time. For milk of reasonably good quality, 0.03 to 0.05% of pure hydrogen peroxide may be used to extend the keeping quality by at least 5 hours, depending on a number of conditions, such as temperature, catalase content of the milk, presence of heavy metals, type of contaminating micro-organisms, etc. The hydrogen peroxide either inhibits the growth of micro-organisms or kills them. Since a number of these organisms will survive the milk being treated with the preservative, this method is called 'temporary preservation', thus indicating that it should be followed by a proper heat treatment, unless products are to be deliberately manufactured from the raw milk (some cheese varieties), or no heat treatment facilities are available.

Hydrogen peroxide is more effective at increased temperatures, but – on the other hand – the generation time of micro-organisms at lower temperatures is longer. Heavy metals and high catalase contents will soon inactivate the preservative.

Anaerobic and coliform bacteria are more resistant than lactic acid and aerobic bacteria. Not all pathogens are equally sensitive to this preservative, which is another reason for considering the hydrogen peroxide preservation as a temporary measure.

Before the milk is distributed or processed all the hydrogen peroxide should be inactivated, either by adding catalase, or by heat treatment. Small quantities of hydrogen peroxide do not affect the milk constituents, with the exception of some amino acids and some vitamins that are easily oxidized, such as vitamin C.

LP preservation. A more recently developed method also making use of hydrogen peroxide – but in much smaller quantities than the method described above – differs markedly from the traditional method. It does not directly interfere with the growth of micro-organisms, but it activites the antibacterial potential of the milk. In this method (lactoperoxydase or LP preservation) hydrogen peroxide is reduced and thiocyanate ions are oxidized by the enzyme peroxydase. This leads to the production of certain compounds with an antibacterial capacity. The enzyme is available in milk in abundance. Although thiocyanate is a normal constituent in milk, the available quantity is not sufficient for proper LP preservation; the quantity largely depends on the feeding of the animal. Certain bacteria in milk produce small quantities of hydrogen peroxide, but the quantity of oxygen that can be provided is too small for the oxydation process in the LP system.

For a proper LP preservation, very small quantities of thiocyanate (0.0015%) and hydrogen peroxide (0.00085%) must be added to the milk. These quantities are sufficient to preserve milk at tropical temperatures for about 8 hours, whilst the preserved milk can be easily kept overnight at temperatures of 15 to 20 °C; at temperatures of 4 °C, the milk can be kept for a few days without spoiling.

The small quantities of hydrogen peroxide are consumed during the preservation period or are destroyed during pasteurization. The milk does not need to be treated with catalase. A small quantity of the thiocyanate will remain in the milk, even after heat treatment, but this quantity is harmless to health. (Human salvia contains far larger concentrations.)

Thermization of milk

It will be useful to give milk that has to be stored over a long time, for instance longer than two days, a better protection against the development of bacteria (psychrotrophic bacteria) than can be achieved by merely cooling the milk to a low temperature. Thermization is a suitable treatment. This is a heat treatment of an intensity that destroys most of the psychrotrophic bacteria. By destroying Gram-negative rods, the production of the very heat-resistant lipases and proteinases is prevented (Section 6.5).

Thermization does not destroy the enzyme phosphatase in milk; consequently, thermized milk will show a positive phosphatase reaction (Section 12.1). The bacteriostatic properties of the milk are hardly affected by thermization. Whey proteins are not denaturized.

The thermization process involves applying time-temperature combinations that are equivalent to a heat treatment of 15 seconds at 63 to 65 °C. For milk of a very poor quality the temperature may be raised to 70 °C, but such a treatment can already be considered as a very mild form of pasteurization.

Thermization should be applied as soon after milk production as possible; it may take place at the chilling centre even before transportation of the milk, if proper facilities are available.

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3.6 Milk collection

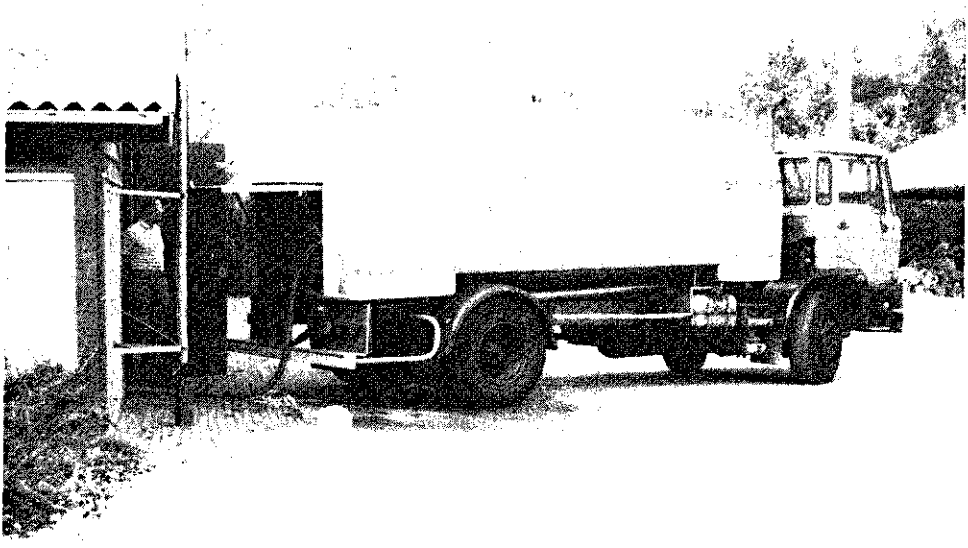
Milk for industrial processing can be taken to the dairy plant by the farmers themselves, or it can be picked up by the plant. In both cases it is possible to put the collection activities out to contract to third parties, e.g. professional transporters.

Because of organizational or economic difficulties it may be troublesome to collect milk in areas far away from the plant and to take it directly to the plant. In such cases, especially if there are many small suppliers, it will be preferable to take the milk to a collection point first and to transport it from there to the dairy plant. This system may even have advantages in areas not too far away from the plant, as it allows milk deliveries to the dairy plant to be spread out over the day. Moreover, congestions of individual suppliers at the plant can be avoided. A collection point can merely be an open spot along the roadside or a regular collection centre with dairy and auxiliary equipment, and laboratory and permanent or part-time staff.

If milk has to be transported over long distances and it will consequently take much time to reach the dairy plant, it is advisable to cool the milk on the farm or in the collection centre before transportation. At the same time, this also enables the plant to organize an efficient system of collection and transportation. Since the milk is cooled, it can be picked up at the farm or the collection centre at any hour of the day without the risk of spoilage; in contrast, uncooled milk must be picked up as quickly after milking as possible, and this leads to peak hours of operation.

Milk pick-up and transportation

Milk in cans. Milk that is available in cans, whether on the farm or at the collection centre, is usually picked up and transported by trucks. The cans should be protected from the sun while they are at the roadside awaiting collection, and during transportation. It is advisable to use insulated or even refrigerated trucks to transport cooled milk in cans over long distances and under high ambient temperatures.



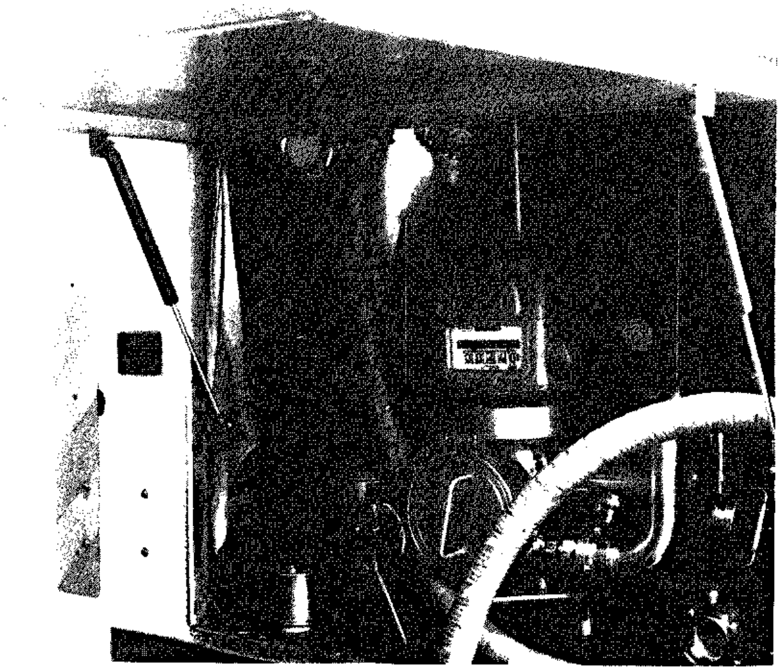


Fig. 16. Tank truck for bulk milk pick-up. Top: tank truck with hose (at the back) connected to the farm tank. Bottom: opened cabinet at the back of the tank truck, showing the milk meter. Photo's: H. Oosterhuis.

Milk in bulk. Milk available in bulk, for instance in farm-tank coolers or in storage tanks, should be picked up in bulk. It is not good practice to use cans to transport milk that is already available in bulk tanks, because there is an extra risk of contamination; furthermore, the temperature of milk in cans is more difficult to control than milk in bulk. Moreover, the filling, and, later on, the emptying and sanitizing of the cans takes much labour and is costly.

Truck-mounted tanks or road tankers can be used for the transport of milk in bulk. The tanks should be insulated and may be covered by a shield to protect the milk against an increase in temperature. The shield is of special importance under conditions of fierce sunshine. On the farm or at the collection centre, the 'truck-tank' is connected to the storage tank by a hose, and the milk is pumped over.

Controlling milk for quantity and quality

As soon as milk in cans is received at the dairy plant or its collection centre, the quantity will be measured, the quality will be checked and samples will be taken for laboratory testing.

In the case of bulk milk pick-up, the driver of the truck must act as a milk collecter. Before the milk is pumped over from the farm tank to the truck tank, he must:

- check the acceptability of the milk;
- take samples for laboratory testing after the milk has been thoroughly mixed;
- measure the quantity of milk (this can be done with a dip stick in the farm tank or with a flow meter mounted on the truck).

After emptying the farm tank, the truck driver should rinse the tank with cold water. The sanitization of the farm tank is the task of the farmer. After sanitization, the tank should be properly drained to prevent the next load of the milk from being diluted.

Mixtures of milk in truck-tanks, received at collection centres and dairy plants must also be measured, checked and sampled. Even if the centres belong to a dairy plant, such procedures are important for the technical administration of the plant and the control of 'the internal efficiency'. Before bulk milk is sampled, the contents of the tank should be thoroughly mixed.

Special 'tank trucks' have been built for picking up milk at farms. These tanks are equipped with a hose, a milk pump, a filter, a milk-flow meter, sampling equipment and a refrigerated cabinet for the sample bottles (Figure 16). To pick up milk in cans, the truck may be equipped with a special hose to transfer the milk from the cans to the 'truck-tank', or with a small dump tank and a weighing device. The additional equipment needed for this type of milk pick-up truck is usually housed in a special cabinet at the rear end of the tank. Tank trucks have been designed with an ice-water system for cooling the milk during transport.

For a bulk-collection system to be set up, the farms must be accessible, even to a fully-loaded truck.

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4 Auxiliaries

In addition to dairy processing equipment, dairy plants need certain auxiliaries. Although it is beyond the scope of this book to discuss these auxiliaries in detail, this chapter will deal with some major principles concerning the supply of electricity, water, steam and refrigeration, and the disposal of effluents. Full and detailed information can be found in manuals and in information bulletins produced by the suppliers of equipment.

4.1 Electricity

All dairy plants need electric energy for lighting, power, control of equipment and sometimes for air conditioning. Electric motors are required for all sorts of dairy equipment, such as milk pumps, can and bottle washers, packing machines, conveyors, etc., and also for the refrigeration system, the boiler house, the water supply and the compressed-air system.

In general, it is usually simpler and – if all expenditures are taken into consideration – cheaper to purchase electricity from outside, i.e. from a public (occasionally, a private) supplier, than to generate power at the plant. Only in cases where the costs of power from outside are prohibitive or where the supply is unreliable or insufficient, is it advisable to use factory-generated power from diesel engines or from gas or steam. If an adequate capacity of electricity is not available or its availability fluctuates with variations in the load on the utility lines of the outside supplier, a stand-by generator will be required.

It may also be advisable to operate a factory generator during peak hours to compensate for a poor load factor. Generally, a high tension supply is required.

Lighting circuits commonly use voltages of 110/120 or 220 V, whereas power circuits require higher voltages (usually 220, 360 or 440 V). Circuits of the alternating current system may be arranged in single-phase, or two-phase and three-phase. The single-phase system is used for light, heating and certain motors. Three-phase current is generally used for power supply.

Further reading

See Section 4.6

4.2 Water

Dairy plants require large amounts of water, mainly for cleaning and cooling, but also for processing. In general, the water should be of satisfactory quality, that is it should be suitable for the purpose it is intended for.

Water for cleaning should be very pure by bacteriological and chemical standards. The chemical composition should not make it necessary to increase the use of detergents (i.e. very hard water should be softened). The water should not leave any deposits on the surfaces that have been washed. Bacteriological purity is required to prevent contamination. It is essential that water used for final rinsing meets high bacteriological standards. Moreover, it should not have an unsatisfactory taste, odour or colour, or have a high acidity. It must be free from toxic compounds and preferably be low in oxygen and carbon dioxide content.

Water used for processing, as for instance in butter and cheese making, or in the production of diluted milk drinks like ayran, should meet the highest standard, i.e. potable quality, because it comes into direct contact with the products.

Water destined for the refrigeration system and boilers should be free from foreign matter that can be deposited on tubes and other surfaces. It should not contain chemical compounds that could cause scale formation or corrosion. In this case, the bacteriological quality is not so crucial.

Absolute purity seems less important for water that is used in coolers and heat exchangers, for cooling the condensors of refrigeration plants, in evaporators and for similar applications. Nevertheless, it can be risky to allow contaminated water to enter a dairy plant, even if it is discharged into drains after it has been passed through a completely closed system.

The water must be free from heavy metals, not only because many of them may be harmful to human health, but also because many give technical or technological side-effects. Iron may cause stains on floors and equipment. Minute quantities of copper catalyse oxidation processes in milk and milk products. Parts that come in contact with milk and milk products must not be made of copper; the same applies for water-piping systems, either for processing and cleaning water, or for boiler water.

The dairy plant can buy water from the public supply, or obtain its own water. Mains water, if available, should be of potable quality. Nevertheless, it is advisable to check the chemical and bacteriological quality regularly. The bacteriological quality of such water may be satisfactory, but the chemical composition may have to be corrected. Water often has to be treated for hardness.

If the water supply is irregular or does not meet the hourly demand during peak hours, it will be necessary to construct water-storage tanks that will fill up while the plant is not operational and/or when water is available.

If the public supply is limited or very expensive, the dairy plant may be supplied from a private well, provided sufficient water of satisfactory quality can be found. This may require deep drilling. Water from sufficiently deeply drilled wells, which is generally bacteriologically very pure, can become contaminated at the top of the well. The well cap and the top lining that comes into contact with the contaminated soil are very vulnerable to pollution. The well casing must be properly watertight, to prevent any water from leaking into the well, and hence to eliminate the danger of harmful bacteriological contamination. It can be seen that open wells are difficult to protect against pollution, especially if they are accessible to third parties. Dairy plants may decide to have one or more private wells and to be connected with the mains too.

Water used for cleaning will be discharged as waste, but cooling water can be reused if water is scarce. This requires special facilities like cooling towers or spray ponds where water can give up heat.

Only if the water is sufficiently cool will a first-stage cooling of milk and milk products in plate or tube exchangers prior to refrigeration with a refrigerant like ice-water be effective or worthwhile. The maximum acceptable temperature depends amongst other things on the temperature of the milk or milk product offered for cooling, and the temperature to which it must be cooled, but – as a rough indication – the water temperature should be below 14 °C. For condensors, higher temperatures are acceptable, but the capacity of the installation will decrease with increasing water temperature.

Farms, collection centres and plants not connected to the mains and unable to draw water from a well may encounter considerable difficulty in finding an adequate supply of suitable water. The use of surface water from rivers, lakes and ponds should only be considered as a last resort for purposes other than cooling. Surface waters may be seriously polluted and contaminated, and the risk of bacteriological contamination in general and contamination with pathogens in particular is very great. A water-treatment plant has to be installed to purify surface water. This may present serious complications and high investments for farmers and processing units.

Bacteriological treatment of water

In all cases where the bacteriological quality of the water is insufficient or doubtful – this may also be the case with water from the public mains – special treatment of the water is required, either by pasteurization or by the use of chemical disinfectants. Treating the water with 10 ppm active chlorine is generally sufficient, but higher concentrations may be found necessary after bacteriological examination of the water after treatment. Water containing organic matter is particularly likely to require higher concentrations. However, water containing high concentrations of chlorine will have an unpleasant taste. Care should be taken, because chlorine is very corrosive to many metals!

Treatment of hard water

Water often contains salts. This causes problems whenever the water is used for cleaning or supplying boilers. These salts contribute to the so-called hardness of water[1] A

[1] Regardless of the chemical constituents, the degree of hardness is usually expressed in terms of ppm calcium cabonate equivalents. Thus, 1 °H ~ 1 mg calcium carbonate per litre of water.

Table 7. Classification of water according to hardness.

°H	Quality of water
< 50	soft
50 – 100	moderately soft
100 – 150	slightly hard
150 – 250	moderately hard
250 – 350	hard
>350	very hard

scale for the classification of water according to the hardness is given in Table 7. The salts in hard water may neutralize part of the alkaline detergents (Section 13.1) and cause precipitates or scale upon heating.

Calcium and magnesium bicarbonates precipitate at temperatures of 80 °C or higher. These deposits have the character of a flocculate and cause few difficulties. In boilers where pure water evaporates in the form of steam, the deposits will accumulate in a sludge, which must be removed by blowing off the boiler.

Far more troublesome is the so-called permanent hardness, which is caused by the presence of calcium and magnesium salts of sulphuric acid, silicates and chlorides. These compounds may cause scale formation on heated surfaces. Such water needs to be softened. There are two possible methods of doing this:

– Precipitating the calcium and magnesium by adding softening compounds, like trisodium phosphate, which leave the precipitated minerals suspended in the water without the risk of deposition and scale formation.

– Cation exchangers, usually substituting sodium for the calcium and magnesium. The treated water still contains minerals, but these do not cause hardness and do not give rise to scale formation.

Before installing a water-softening system, seek technical advice. This is especially important if the water is used for feeding boilers. Very soft water is usually corrosive.

Further reading

See Section 4.6

4.3 Hot water and steam

Hot water is used for processing and cleaning. Steam is used to sterilize equipment and in other sanitization procedures, for instance in can and bottle washers. Furthermore, it is utilized in heat-treatment procedures, as in heat exchangers and in systems with direct steam injection.

Hot water

On farms, hot water for cleaning and processing can be produced by boiling water over an open fire. Hot-water boilers heated by gas or electricity – if available – may be found more practical.

There are several ways of producing hot water in larger collection centres and in processing units with steam boilers, such as:

– For an incidental supply of small amounts of hot water, steam may be blown into a reservoir containing cold water, or steam and cold water can be mixed in a special mixing tee.

– For a permanent supply of larger quantities of hot water, the installation of a water tank with steam coils may be preferred. The temperature of the water can be controlled automatically. The hot water is passed through a pipeline system to the places in the plant where it is needed.

Steam

A steam boiler generally consists of a closed chamber, usually in combination with a tubular system, in which steam is generated. The heat is produced in a heater by burning coal, oil, gas or any other fuel in a furnace. In dairy plants the furnace is usually an integral part of the boiler, but it may be separate from it; most of the small and medium-sized boilers are of the 'integral' type.

Most boilers can be classified either as fire-tube or water-tube boilers. In the fire-tube ones (Figure 17) the hot gases produced in the furnace pass through the tubes, heating the water outside the tubes. In the water-tube ones the water passes through the tubes, where it is heated from outside. The fire-tube boilers are mostly found in small and medium-capacity plants; they operate at lower steam pressures. Water-tube boilers are especially suited for high capacities and high pressures; they are commonly used in large power plants. The total surface of all pipes where water comes into contact with hot gases is called the heating surface.

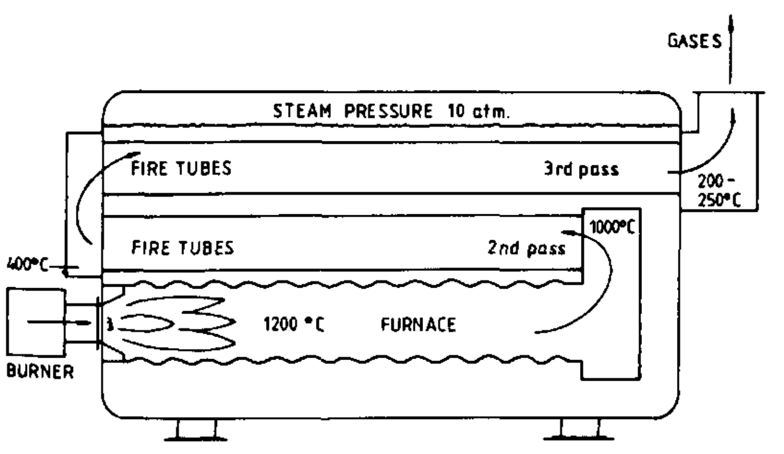

Fig. 17. Fire-tube boiler. Courtesy: K. Hagoort Produktie Mij. B.V.

Not all the heat developed by combustion of fuel in the furnace of a steam boiler is used for steam production. Some of it is lost with waste gases and by radiation. The percentage of energy available in the fuel utilized in steam production gives an indication of the efficiency of the boiler. Efficiency figures are generally based on optimal conditions of stoking and a regular use with no variations in load. Such conditions are seldom realized in practice. For small-capacity simple boilers which are irregularly loaded, an efficiency of about 70% seems normal. This percentage can be considerably increased under favourable conditions of operation, especially if modern high-capacity boilers with special provisions for efficient operation are used.

Special steam generators have been developed that contain only a small quantity of water in comparison with their heating surface. Full steam production can be reached more quickly with these generators than with the conventional type of boiler. They may be used for full steam supply in dairy plants or for supplementary steam production during peak hours.

Electric steam boilers are ideal in areas where electricity is very cheap. They offer technical advantages and have a very high thermal efficiency (e.g. 99%).

Steam contains a large amount of heat. To raise the temperature of 1 kg of water by 1 °C requires 1 kcal of heat. This means that 1 kg of water at 100 °C contains 100 kcal (reckoning from 0 °C); but 1 kg of steam contains about 540 kcal more under atmospheric pressure. This extra heat, known as latent heat, becomes available as the steam condenses. The high heat content of steam (100 + 540 = 640 kcal at atmospheric pressure) enables large quantities of heat to be transported and transferred. Unfortunately, steam has a high specific volume. Table 8 shows to what extent the tempera-

Table 8. Properties of saturated steam.

Absolute pressure (atm, kg/cm^2)	Temperature (°C)	Specific volume (m^3/kg)	Heat of the liquid (kcal/kg)	Latent heat steam (kcal/kg)	Total heat steam (kcal/kg)
0.50	80.9	3.30	80.8	550.8	631.6
0.60	85.5	2.78	85.4	548.0	633.4
0.70	89.5	2.41	89.4	545.5	634.9
0.80	93.0	2.13	93.0	543.2	636.2
0.90	96.2	1.90	96.2	541.2	637.4
1.00	99.1	1.73	99.1	539.4	638.5
2.00	119.6	0.90	119.9	525.9	645.8
3.00	132.9	0.62	133.4	516.9	650.3
4.00	142.9	0.47	143.6	509.8	653.4
5.00	151.1	0.38	152.1	503.7	655.8
6.00	158.1	0.32	159.3	498.5	657.8
7.00	164.2	0.28	165.6	493.8	659.4
8.00	169.6	0.24	171.3	489.5	660.8
9.00	174.5	0.22	176.4	485.6	662.0
10.00	179.0	0.20	181.2	481.8	663.0

ture and the heat content of steam increase and the specific volume decreases with an increase of absolute pressure.

The operating pressure of a steam boiler depends mainly on the processing requirements. Milk powder plants where steam is used for heating air require much higher steam pressures than normal milk plants. In general, the pressures may vary from 7 to 11 atmospheres, although many (especially simple plants with a low capacity) operate boilers at a lower pressure. In the dairy plant, the pressure of steam can be lowered by reducing valves.

Whenever steam condenses, giving up its latent heat, the condensate must be returned to the boiler if this is economical. It can be temporarily stored in a condensate return tank. Utilizing the condensate has a number of advantages, mainly because the water is pure and has a higher temperature than fresh water, thus providing a saving in water treatment and fuel. Sometimes, the condensate contains oil from leakages, or oxygen; these must be removed. Since only part of the steam will be returned to the boiler in the form of condensate, fresh water must be supplied regularly. This water must be very pure (Section 4.2).

Further reading

See Section 4.6

4.4 Refrigeration

Refrigeration is one of the most important processes in the dairy industry. It is the process of removing heat from a product as a means of:
- preserving the product by cooling it to a sufficiently low temperature;
- obtaining a product with specific qualities, e.g. ice cream.

Refrigeration can be achieved in different ways, utilizing:
- water,
- water ice or dry ice,
- ice/salt mixtures,
- in-place refrigeration equipment.

Cooling with water can be achieved in several ways, as discussed in Section 3.4.

Ice

If ice is available, it can be utilized for small-scale cooling. If the ice is bacteriologically and chemically pure, it can be added directly to the product. This is a very rapid and most efficient way of cooling, but it will dilute the product. Indirect cooling can be obtained by putting containers of the product in ice, or, conversely, by placing containers of ice in the product (e.g. ice-cones in milk: Section 3.4).

The cooling capacity of ice is very high, because of the availability of latent heat, that is the heat (actually, the cold) given up by the ice during melting without a change in temperature. One kg of ice at 0 °C gives up 80 kcal during melting to water at 0 °C. The sensible heat is the heat associated with changes in temperature during heating or cooling.

Example: If 30 kg of milk in a 40 l milk can must be cooled from 30 °C to 8 °C, using an ice-cone with ice, the final temperature of the ice-water being 4 °C, the required quantity of ice can be found as follows:

– Latent heat available per kg of ice: 80 kcal; sensible heat available per kg of ice water: 4 kcal; total heat absorbed by 1 kg of ice: 84 kcal.

– Kilocalories to be removed from 30 kg of milk: $30 \times (30-8) \times 0.93 = 614$ kcal[1]

– Quantity of ice required: 614:84 = about 7.5 kg. It is assumed that there are no cold losses and that the temperature of the ice is 0 °C. Usually this temperature is lower.

Dry ice

Carbon dioxide is available in cylinders, where it is kept under high pressure. The gas is allowed to escape by opening the valve of the cylinder. The temperature of the gas will be lowered considerably as a result of its sudden expansion in the atmosphere. The gas solidifies as an effect of this reduction in temperature, thus forming 'dry ice'. This dry ice sublimates (evaporates) in an atmosphere of carbon dioxide at a temperature of almost −80 °C, delivering about 140 kcal latent cold per kg.

Dry ice must be handled with special care. It should not be packed in closed containers, other than the cylinders mentioned above, and it should not come into direct contact with the skin.

Ice/salt mixtures

Sometimes, temperatures below 0 °C are required for small-scale operations, e.g. the production of small quantities of ice cream. This can be easily done by mixing salt and ice, and putting the product to be frozen in a container which is then put in the mixture. Increasing the ratio of salt to ice will lower the temperature. The minimum temperatures that can theoretically be reached in ice/salt mixtures of different concentrations are given in Table 9.

Artificial refrigeration

In artificial refrigeration, liquified gases with a low boiling-point boil and evaporate under reduced pressure at the surface, e.g. a separation wall, that is to be cooled. The heat required for boiling and evaporation is absorbed from the environment, in this

[1] The specific heat capacity, i.e. the quantity of heat required to raise the temperature of 1 kg of a substance by 1 °C, is 1.00 for water; that of milk is 0.93.

Table 9. Minimum temperatures of ice/salt mixtures.

Salt content of mixture (%)	Temperature of mixture (°C)
0	0
5	− 2.8
10	− 6.7
15	−11.7
20	−16.9
25	−23.3

case from the product on the other side of said surface. The vapours formed by evaporation are collected again and liquified by compression and cooling in a compressor and condensor. This system of refrigeration using a circulating gas is called the refrigeration cycle (Figure 18).

Condensors are actually heat exchangers, where the heat of the compressed gas is absorbed either by water (water-cooled condensors) or by air (air-cooled condensors). The choice of the type of condensor usually depends on the investment and the opera-

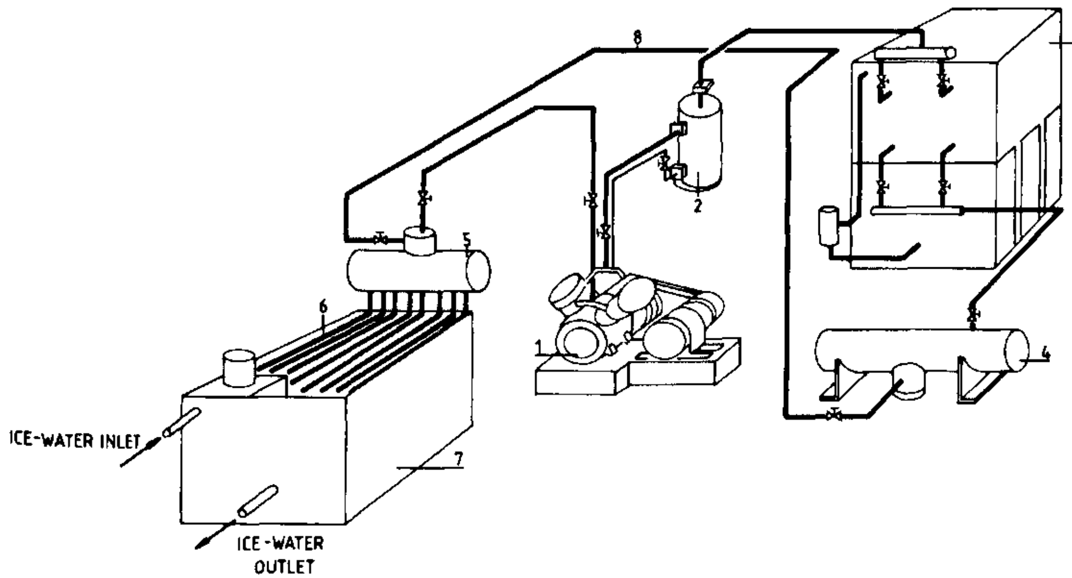

Fig. 18. Refrigeration cycle with ice-water bank. The vapours formed by evaporation in the tubes of the submerged evaporator (6) are compressed in the compressor (1) and (passing through the oil separator, 2) are transferred to the condensor (3), where they are liquified. The liquid is collected in the liquid receiver (4). Through a pipeline (8), the liquid is transferred to a liquid separator (5), where it is available for evaporation in the submerged evaporator (6) in the ice-water tank (7). Courtesy: Grenco N.V.

tional costs, but under tropical conditions sufficient quantities of water may not be available and air-cooled condensors will have to be used under all conditions. In this case the high ambient temperature has to be taken into consideration, because the warmer the air, the higher the liquification pressure of the condensed gas and its temperature: this adversely affects the capacity of the installation.

There are two systems of artificial refrigeration: direct and indirect refrigeration. Direct refrigeration includes all systems where the evaporating refrigerant transfers its cold directly to the milk or the dairy product. Indirect refrigeration includes all systems where an intermediate medium, known as a heat carrier, is used. This heat carrier is cooled to a low temperature in the refrigeration cycle and from there pumped through insulated pipelines to all places in the plant where it is needed for cooling. At those points the carrier transfers its cold to the product to be cooled, and is then returned to the refrigeration cycle.

Indirect refrigeration

In systems of indirect refrigeration the evaporator of the refrigeration cycle is situated in a reservoir with the heat carrier. The evaporator consists of a system of coils or pipes in which the refrigerant evaporates, thus cooling the heat carrier.

Brines consisting of solutions of certain salts, like calcium or sodium chloride, have the advantage of allowing for cooling to temperatures below 0 °C (Table 10). These salt solutions have the disadvantage of being corrosive, especially if acid and in the presence of air (oxygen). Protective chemical compounds (an alkaline solution of sodium bichromate – actually sodium chromate) can be added.

Indirect refrigeration systems allow cold to be stored in the reservoir containing the heat carrier. The production of cold can be extended over a long period, enabling a small compressor to be used. The storage of cold allows for heavy cold loads to be supplied for short periods.

The energy efficiency of the indirect system is lower than that of the direct system. The quantity of cold that can be accumulated in brines is limited.

The capacity of a refrigeration system can be increased considerably by making use of an ice bank. Such a bank consists of a large fresh-water tank containing an evaporator consisting of a system of coils. As a result of the low temperature of the evaporating

Table 10. Freezing point of calcium chloride brine.

$CaCl_2$ content (g/100 g of brine)	Freezing temperature (°C)
14.5	−10
21.3	−20
25.1	−30
27.8	−40
29.9	−55

refrigerant, ice will freeze on the surface of the coils, thus forming a large stock of cold. When large amounts of cold are required, the ice will thaw and supply the required quantity of cold.

Direct refrigeration
The direct system is simpler than the indirect system. It is cheaper and in most cases heat can be transferred quicker. The direct system has the disadvantage that it needs a compressor with a capacity adjusted to the maximum requirements of cold supply at any one time. It requires a comparatively large installation and can be responsible for unfavourable load factors in electricity consumption.

Nowadays, coolers in cold-storage rooms are generally of the direct type. They may be fed from a central refrigeration cycle, but in modern dairy plants they usually form independent units. The cooler or evaporator can be of various designs, but will generally consist of a 'nest' of coils enclosed in a metal casing. A fan draws the air of the cold store at high velocity through the nest of coils.

Further reading

See Section 4.6

4.5 Automation and alternative energy supply

Automation and mechanization
In contrast with the situation in countries with a highly developed industry, the costs of labour are comparatively low and the costs of energy relatively high in many countries with a developing dairy industry. Moreover, energy supplies are not always reliable in these countries. If, furthermore, the capacity of the processing units is low and the servicing facilities limited, there is sufficient reason to aim at:
- a limitation of mechanization and automation;
- the provision of low-energy operations and stand-by facilities.

It must be ascertained whether extra expenditure on automation and mechanization to replace human labour is economically justifiable. Furthermore, some countries have a policy of providing as much employment as possible, provided that this does not lead to an increase in the prices of the products.

If, for certain reasons, e.g. the desire to be independent of the human factor, preference is given to automation and mechanization, provisions should be made available so that in cases of failure, temporary manual operation remains possible. Whenever dairy plants are established, the costs and risks of sophisticated equipment must be given serious consideration.

Alternative energy supply
Stand-by facilities in case of emergencies, such as a stand-by generator for electricity,

must be available. As an added safeguard, certain electrically operated equipment could be made suitable for manual operation.

Alternative sources are especially suitable for covering some, if not all, of the energy requirements of simple and low-capacity dairy plants. The feasibility and viability of solar energy is currently receiving much attention. The roof of the plant can be covered by metal sheets that collect solar energy and transform the energy into heat. This heat is transferred to tubes in which water circulates. The hot water is stored and can be used for heating milk, cleansing, etc. Since solar energy will not always be available, there must be a back-up source.

Energy can be saved by making use of gravity for the transportation of milk by arranging the processing floors at different levels in a cascade-type dairy plant. This avoids the necessity of having many milk pumps.

On farms and in collection centres and dairy plants, heat can be recovered by using the hot compressed refrigerant in refrigeration cycles (Section 4.4) to heat water, before the refrigerant is led to the condensor. The hot water can be used for heating and cleansing.

Further reading

See Section 4.6

4.6 Dairy effluents

Milk plants generally produce large quantities of effluents, which principally consist of used detergents, process effluents and relatively clean water from coolers. Sometimes, small quantities of such effluents can be discharged into streams, rivers and other open waters, but larger quantities can easily create serious pollution problems.

Discharge of the effluents to a local sewer is the most convenient way of disposal, but often the fees to be paid are high. Sometimes, public authorities object to the disposal because of the nature of the impurities. If no public sewage system is available or the dairy effluents are not allowed into this system, the plant must establish its own facilities for the treatment of its effluents, like septic tanks, biological filters or installations for spraying the effluents on land.

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5 Reception and pretreatment of milk

5.1 Reception and storage

The facilities in the milk reception section of a collection centre or a dairy plant will mainly depend on:

- the way the milk is offered;
- the quantity of milk to be received.

Milk may be offered in cans or in bulk. Cans will usually have a capacity up to 40 l, although cans with a capacity up to 200 l are used. The latter are too heavy for manual handling and require special facilities for lifting and transport. Milk in bulk is offered in containers with a capacity over 200 l. Such containers are usually mounted at farms, collection points and other places, or are fitted on carriers like trucks, and are either removable or fixed.

Milk offered in cans is in most cases supplied by individual farmers or other owners of milch animals. This milk is usually not deep-cooled, but even if it is, a considerable rise in temperature is to be expected during handling and transport if the ambient temperature is high. When planning a milk reception for milk in cans it seems realistic to assume an intake temperature of 30 °C, to be on the safe side.

Milk offered in bulk usually comes from places where facilities for deep-cooling are available. Since the amounts are large and the containers are generally insulated, the rise in temperature during handling and transport will be slight. Nevertheless, an increase of a few degrees Celsius during 'pumping over' to and from the container will be unavoidable and an average intake temperature of 10 °C should be reckoned with.

Unless the milk can be heat-treated immediately after intake, all milk should be cooled or recooled to a temperature as low as 4 to 5 °C. In some dairy plants, the milk is thermized immediately after intake, i.e. before cooling or recooling (Section 3.5).

5.1.1 Intake of milk in cans

Milk in cans can be picked up by the dairy plant at the farms or at certain collection points, or can be delivered to the dairy plant or its collection centre by the farmers themselves. Sometimes third parties are engaged. In all cases, the time between milking and reception should be as short as possible.

If milk in cans is picked up at the farm, milking must start as late as possible before the collection vehicle arrives. On the other hand, the collection should be organized so as to allow the vehicle to arrive at the farms soon after the majority of the farmers have normally finished milking. It is also very important that the collection is arranged in such a way that the collection vehicles arrive at the collection centre or the plant at intervals not much longer than the time required for unloading and handling the cans at the milk reception.

If milk is supplied by the individual farmers, efficient organization of the milk intake is even more difficult, and queues of milk suppliers are no exception. In order to relieve the dairy plant, collection centres are sometimes set up fairly close to the plant.

Since cows at all farms are usually milked within a short period of time, for instance within a period of two hours, collection of milk in cans should be completed within the same period of time, i.e. generally within two hours.

The necessary capacity of a milk reception mainly depends on:

- the total quantity of milk supplied;
- the lean-flush ratio of milk supply;
- whether the milk intake is once or twice a day;
- the size and the filling of the cans, or other receptacles.

The capacity of the collection facilities should agree with the maximum quantity of milk that can be expected in one delivery in the flush season.

To control the quality of the milk, it is advisable to collect milk twice a day, that is in the morning and in the afternoon. A once-daily collection is only acceptable if the evening milk is properly cooled and stored at the farm, or if the evening milk is kept on the farm and is not made available to the dairy plant. If the milk is received twice a day, morning supplies will generally prove to be larger than evening supplies.

The time required to collect a certain quantity of milk will also depend on the number of farmers and the quantity of milk they offer. A large number of farmers offering small quantities of milk in small cans or other receptacles, or in cans or receptacles that are only partly filled will require a large intake capacity.

To facilitate handling, the cans should be standardized. Cans with a capacity of 30 or 40 l are mainly used.

The required capacity of a milk reception outfit can be calculated according to the following example:

- Assumptions: daily milk intake 30000 l of which 2/3 in the morning and 1/3 in the evening; all milk is supplied in cans with a capacity of 30 l each, 75% full, on average; period of intake 3 hours with 15% loss of time for waiting periods between unloading the various transport vehicles.
- Calculation: morning intake 20000 l; on average, one can contains 22.5 l; effective reception time about 153 minutes.
- Capacity needed: $(20000:22.5) \times (60:153) = 350$ cans per hour.

Operation of can reception

A number of operations are performed in the reception section, such as checking the quality of the milk, sampling the milk for laboratory testing, and measuring the quantity of the milk. But the washing of the cans is also an essential operation of this sec-

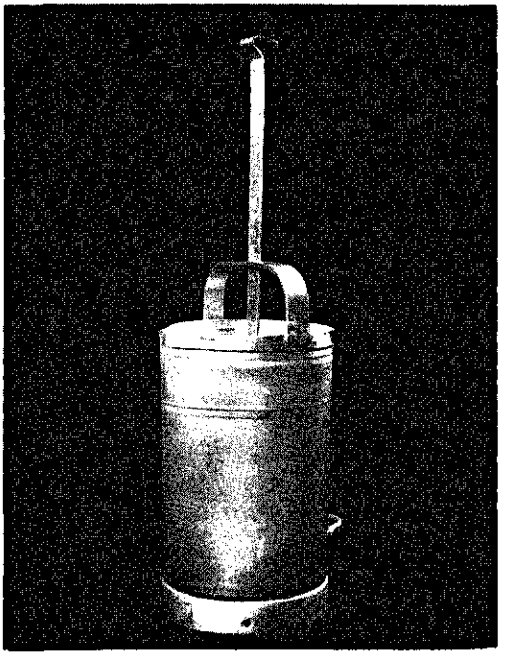

Fig. 19. Milk container with measuring stick. Courtesy: Alfa Laval Food Engineering AB.

tion. Returning sanitized cans to the milk supplier more or less guarantees that the fresh milk will not be contaminated by cans that are improperly sanitized (if at all) on the farm.

There are many designs for the reception procedure and the manual or mechanized handling of cans. In simple small-capacity collection points or centres, milk may be measured in a standard milk can using a calibrated dipstick (Figure 19), or milk may be weighed in a standard milk can on a scale, or with the use of a steel-yard. Such centres are too small for a regular can washer, but cans can be cleaned manually in a basin with a cleansing agent, or by means of a steam-block (Figure 20). Dirty cans are put upside down on top of this block. A foot pedal operates a strong jet of water, preferably containing a cleansing agent, which washes the inside of the can; this is followed or accompanied by a jet of steam.

Larger-capacity reception centres can be mechanized.

Consider a manual operation suitable for a capacity of 350 cans per hour, which means a handling rate of 6 cans per minute (Figure 21). This can be considered the absolute maximum for a one-line manual operation. Cans are removed from the collection vehicle and placed on a roller conveyor which slopes down slightly towards a weighing machine. On their way to this machine the lids of the cans are loosened and the milk is checked for acceptability. The cans containing poor-quality milk are put aside, the cans with acceptable milk are emptied into the weighing bowl of the weighing machine. The quantity of milk supplied by every farmer is registered.

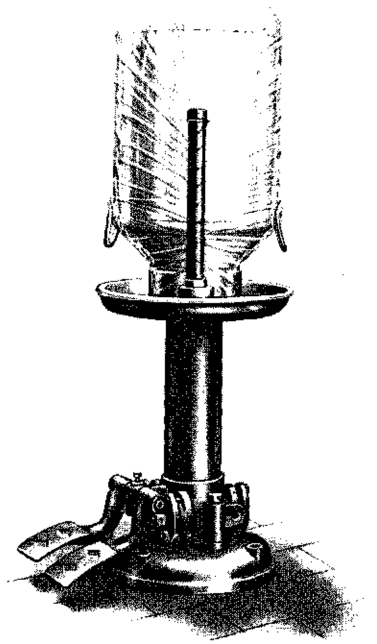

Fig. 20. Steam block for washing cans. Courtesy: Pasilac AS.

Samples for laboratory testing can be taken from the milk in the cans, or from the milk in the weighing bowl. Taking samples from the bowl has the advantage that milk can be easily mixed in the bowl before sampling, if individual milk suppliers deliver two or more cans. Otherwise, composite samples have to be prepared by mixing the samples taken from all cans of every supplier. If most of the supplies are small, i.e. less than one full can, or if no weighing bowl is used, samples should be taken directly from the cans. Taking samples from a bowl has the disadvantage that every supply of milk can be contaminated by a previous supply. This particularly holds if the supplies are small.

The emptied cans are put upside down on a drainage rack. The milk that drains from the cans can be collected for processing. The quality may be poor. The drainage rack is coupled with a straight-line can washer where the cans are sanitized (Section 13.3).

For small capacities, for instance up to 6 to 7 cans per minute, rotary can washers are sometimes preferred over straight-line can washers (Section 13.3).

The weighing machine may have two weighing bowls into which the milk is tipped alternately, through stainless-steel sieves that remove coarse dirt. After the quantity of milk has been registered, the outlet valve in the bottom of the bowl is opened and the milk is released into a dump tank situated under the weighing bowl. While the milk is flowing into the dump tank, the next consignment can be tipped into the other bowl. A double weighing bowl may be necessary to speed up milk collection. It can also be used for sorting out low-quality milk.

Fig. 21. Milk reception. A roller conveyor transports cans of milk to the scales, where the milk is weighed. After emptying, the cans are put upside down on a drainage rack within reach of the rotary can washer in the background (on the right). Photo: M.A. Luijkx.

From the dump tank, milk is pumped through an inline filter and a plate or tubular cooler to a storage tank. The capacity of the cooler should be adjusted to the capacity of the reception. If – as in the example given above – about 8000 l of milk are received in cans per hour, the cooler should have a handling capacity of 10000 l per hour. The cooling capacity depends on the temperature of the milk at the moment of intake.

Manual can reception can theoretically reach capacities of about 10000 l per hour, provided consignments are not too small and cans (capacity 40 l) contain 30 l of milk on average. Higher capacities can be reached in receptions that are automatically controlled. In this case, cans are put on a conveyor that transports them to a weighing machine, where the cans are emptied by being inverted automatically. Thereafter, they continue upside down on the conveyor, through a straight-line can washer and on to the delivery platform for empty cans, after they have been automatically turned upright.

Intake of poor-quality milk

Milk unfit for processing should be rejected and returned to the supplier.

Milk with too high an acidity, but otherwise without serious defects, might be accepted, but be temporarily set aside. Once all milk of normal quality has been received, the cans of poor-quality milk can be emptied and the milk pumped to a separator for creaming. Thereafter, the cream can be neutralized and/or used to make butter or ghee. The skimmed milk can be sent back to the farm or it can be used for the manufacture of second-quality fermented liquid milk products or 'fresh' cheese. It is also possible to neutralize the whole quantity of milk for further processing. The rennetability of milk for cheese-making suffers greatly from the neutralization process. It cannot be expected that products manufactured from very acid or neutralized milk and cream will be of high quality.

If sour milk is to be accepted and processed regularly, special facilities must be provided, such as neutralization and storage tanks, pumps and a low-capacity separator.

Reception of sour cream

Some dairy plants receive cream produced at farms by separation of milk. The microbial quality of such cream is mostly poor, especially because of a high acidity. Cans containing sour cream can be emptied by inverting them on a rack of metal bars over a dump tank. A jet of steam introduced into the inverted cans will facilitate the drainage of the viscous sour cream.

5.1.2 Intake of milk from tankers

Milk tankers, whether they are road tankers or farm-collection tankers, require a special reception bay with facilities for unloading and sanitization.

All milk supplied in bulk must be measured, to verify the quantity. This is done by weighing the filled and the emptied tanker, or by measuring the milk in the tank with a dipstick. Alternatively, a milk meter in the pipeline through which the milk is pumped can be used, or the milk can be weighed in a special weighing tank, or be measured in the storage tanks.

It is often found advisable to take a sample of the milk on arrival and to check its temperature. The milk should be thoroughly mixed before sampling, either manually or mechanically. Sampling for purposes other than checking the acceptability, is also possible in the storage tank, provided the milk has not been mixed with other milk or liquids. If the milk is found acceptable, the tanker is connected by a hose to a high-capacity milk pump, which delivers the milk to a storage tank, preferably in less than 20 minutes.

Sometimes the cooler in the reception centre can be used if the milk has to be recooled, providing that the cooling capacity and the throughput are suitable, and the cooler is not needed at the same time for the cooling of the milk received in cans.

A filter may be placed in the pipeline between tanker and storage tank to remove any dirt still present in the milk.

5.1.3 Storage of raw milk

The raw milk will be stored in insulated tanks provided with agitators and facilities for mechanical sanitization. The desired storage capacity depends mainly on the milk intake programme, the maximum number of consecutive days during which there will be no milk processing (weekends and other holidays), the maximum quantity of milk during the flush season, and the processing programme. From the storage tanks, the milk will be pumped to the pretreatment or processing departments by centrifugal pumps.

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5.2 Platform sampling and testing of raw milk

Samples are taken at the milk reception for testing the raw milk for: acceptability, composition, hygienic quality, and adulteration.

5.2.1 Acceptability

Not all milk supplied to a dairy plant is fit for processing. The quality may be so poor that the milk must be rejected. To sort out such poor-quality milk, a few tests can be performed at the collection place. These so-called 'platform tests' should be very quick to do, so that the operation of the milk reception is not disrupted. This means that only tests that give an immediate result can be used; these tests are:
- acidity tests: alcohol test, clot-on-boiling test;
- appearance tests: smell; colour, dirt, abnormalities.

Acidity

Milk with an above-normal acidity is not fit for the production of high-quality milk products. If the milk is curdled or if it has a sour smell as a result of acid production, it can easily be detected at the reception dock because the milk is defective in appearance and flavour. If only small quantities of acid have been produced, special tests must be performed to sort out milk with too high an acidity. The most important tests are the alcohol test and the clot-on-boiling test.

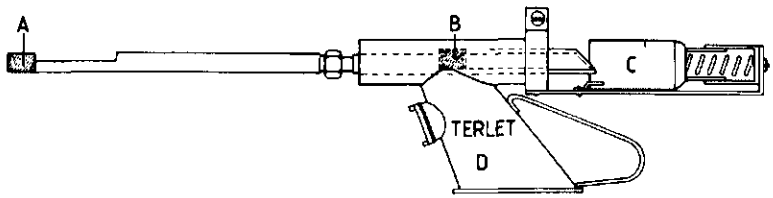

Fig. 22. Milk tester (alcohol test). The tester has to be inserted vertically in the milk, in such a way that a milk sample is collected in cup A. Invert the tester, and the milk will flow into the test tube C. At the same time, an equal quantity of alcohol will flow from the cup B to the tube, where it mixes with the milk. By turning the tester the right way up again, the test tube will be emptied, and cup A will be refilled from the reservoir D. The tester is now ready to test another quantity of milk. A. Sample cup for milk. B. Sample cup for alcohol. C. Test tube. D. Reservoir for alcohol. Courtesy: Machinefabriek Terlet N.V.

Alcohol test. The alcohol test is intended to sort out milk with an increased acidity. For cow's milk, equal parts of milk and alcohol (68%) are mixed. 'Normal' milk, that is milk with a pH greater than 6.4, will pass the test, but milk with a lower pH will curdle. This actually means that, taking alcohol of this strength, a slight acid production is accepted. Colostrum, bad mastitis milk and milk with an abnormal salt balance may curdle, even if the acidity is normal. Using alcohol of a higher percentage than 68% will make the test more sensitive.

The 68% alcohol test is not suitable for all kinds of milk. The salt balance of buffalo's milk, for instance, is such that a slightly increased acidity will cause the milk to curdle. To make the test applicable to all kinds of milk, the alcohol should be adjusted to the 'alcohol stability' of the particular milk. For buffalo's milk, alcohol of 60% is recommended. If cow's milk as well as buffalo's milk, and/or mixtures of the two are received, it is difficult to decide on correct strength of the alcohol. Special devices are available for a quick performance of the alcohol test (Figure 22).

Clot-on-boiling test. Milk with a sufficiently increased acidity will clot on boiling. To perform this test, a small quantity of milk is boiled in a test-tube over a spirit-flame, or heated in boiling water. If the milk coagulates, it is unfit for pasteurization. The milks of different mammals show different acidities on clot-on-boiling. In general, the test is less stringent for cow's milk than the 68% alcohol test, but can be replaced by this test if weaker alcohol (e.g. 60%) is used.

Appearance

Smell. Milk may acquire off-flavours from strongly-smelling materials, either by direct absorption or by indirect transfer through the body of the animal. Bacterial activity may be another cause of objectionable flavours. At the reception dock a flavour test can be performed by smelling the inside of the can immediately after the lid has been removed. Milk with a sour or other objectionable flavour should be rejected.

Colour, dirt, abnormalities. Milk containing blood or large quantities of dirt, often showing an abnormal colour, and high-viscosity or destabilized milk (colostrum and sweet and acid curdled milk) should be rejected.

5.2.2 Composition of milk

Samples must be taken to test the milk for fat content and – under certain conditions – for protein content, if the milk is to be paid for according to its composition. The protein test is elaborate and requires a well-equipped laboratory. The fat test, which can be performed in a much simpler laboratory, will be explained in Section 12.1.

5.2.3 Hygienic quality of milk

Payment for milk on hygienic quality may be introduced for several reasons:
- the manufacture of high-quality products requires high-quality milk.
- a farmer who pays much attention to the quality of the milk should be rewarded accordingly.

Milk that passes the platform tests is not necessarily milk of high hygienic quality. To test the milk for hygienic quality, more elaborate, time-consuming tests must be performed. Actually, for the purpose of complete quality control, all milk should be tested every day, because, unlike samples for fat testing, samples to be used for bacteriological examination may not be preserved. Since daily testing is not economically justifiable, random samples can be taken at irregular intervals, e.g. fortnightly. The number of samples taken, and also the number and the choice of the testing methods will depend on the facilities available and the costs involved. Large-scale examination calls for routine methods that must be neither time-consuming nor costly. It is therefore not feasible to pay for farm milk on the exact determination of its hygienic quality. The results obtained from testing give only a rough idea of the quality of the milk and of the care paid to its production, but they should be used to stimulate farmers to adopt an adequate daily routine of sanitization.

The major tests that can be introduced to evaluate the hygienic quality of milk refer to:
- purity (filter or sediment test),
- bacteriological quality (reductase test or germination number[1]),
- milk cell count,
- smell,
- residues (antibiotics, disinfectants, pesticides, etc.).

The tests can, of course, be combined. They will be discussed, either briefly or in detail, in Section 11.1

[1] Also called: plate count, bacterial count, aerobic count, or colony-forming units.

5.2.4 Adulteration of milk

One of the most lucrative ways of making money is to adulterate milk. This can be achieved by various means, e.g.:

- adding water;
- extracting the fat by removing the cream.

Adding water

The processing of milk with an increased water content means a serious loss to a dairy plant, because water must be received, cooled, pasteurized, etc.) instead of milk. Moreover, it gives a lower yield (less cheese, khoa, milk powder) per kg of milk. If the milk is processed for liquid consumption, an increased water content may mean that the final product does not meet legal standards.

A rough method for detecting added water (Section 1.2) is to measure the density. Milk diluted with water has a lower density than normal milk. However, the density also depends on the fat content and the solids-non-fat (SNF) content, because milk fat has a lower density than water, whereas SNF has a higher density. This means that adding some water to low-fat milk will give a product that has the same density as unadulterated high-fat milk. This reduces the reliability of the test, which can only detect large quantities of water (more than 5 to 10%) with certainty.

The most reliable test of water addition is the determination of the freezing point, which is fairly constant, but varies between milks from different species. Adding water increases the freezing point proportionally, which means that changes in the freezing point enable the amount of water that has been added to be calculated (Section 2.3). In milk that has been kept too long and/or too warm, degradation of milk components (e.g. souring) may lower the freezing point. The freezing point will also be lowered by the addition of large quantities of preservatives, like bichromate, to the sample. It is possible to add certain compounds, such as sugar or salt, to compensate for the decrease of the freezing point caused by adding water. Moderate additions cannot be observed by tasting the milk; special, rather complicated laboratory tests are required.

Extracting fat

If the producer has extracted fat by partially skimming the milk, this can be very disadvantageous to a dairy plant, especially if high-fat products are manufactured, and the production programme is based on full-cream fresh milk with an expected high fat content.

It is practically impossible to detect fat or cream extraction, because the fat content varies greatly between species and individual animals. Moreover, day-to-day variations can be considerable. Only samples with extremely low fat contents give an indication of adulteration. Therefore, this kind of adulteration must be made unattractive by a proper system of payment according to milk composition (Section 12.2).

Further reading

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See also 'Further reading' Sections 12.1 and 12.2

5.3 Pretreatment of milk

Before the milk in the storage tanks is used for the manufacture of dairy products, it can be pretreated in a number of ways (Figure 23). The most important are:
- clarification,
- separation,
- homogenization,
- standardization,
- heat treatment and cooling,
- storage.

It is difficult to discuss the process of heat treatment separately from the production of pasteurized and sterilized milk. Therefore, these subjects will be discussed together in Chapter 6 (Heat treatment of milk and processing of liquid milk).

At the end of this section two special forms of pretreatment will be discussed: centrifugal homogenization, and centrifugal removal of bacteria.

5.3.1 Clarification

Extraneous matter has to be removed from milk. If not, it may appear as sediment in liquid milk, especially after storage, and as dirt in other products.

Filtering is the simplest way to remove impurities, but this has the disadvantage that all milk has to pass through the dirt that accumulates on the filter, and part of the extraneous matter will 'dissolve' in the milk that passes through the filter; moreover, micro-organisms will be washed out of the dirt. Bacteria present in clumps or in dirt particles will be dispersed throughout the milk.

A more efficient (but also more expensive) method is to use clarifiers, which remove impurities by centrifugal force. Clarifiers are very similar to cream separators, as will be discussed in Section 5.3.2 which deals with cream separation. Milk can be clarified at a low temperature, so clarifiers may be positioned in front of the heat-treatment plant or they may be incorporated in the process of heat treatment, e.g. in the regeneration section. Their location will, amongst other factors, depend on the location of the other processing equipment, like separators and homogenizers. Many dairy plants

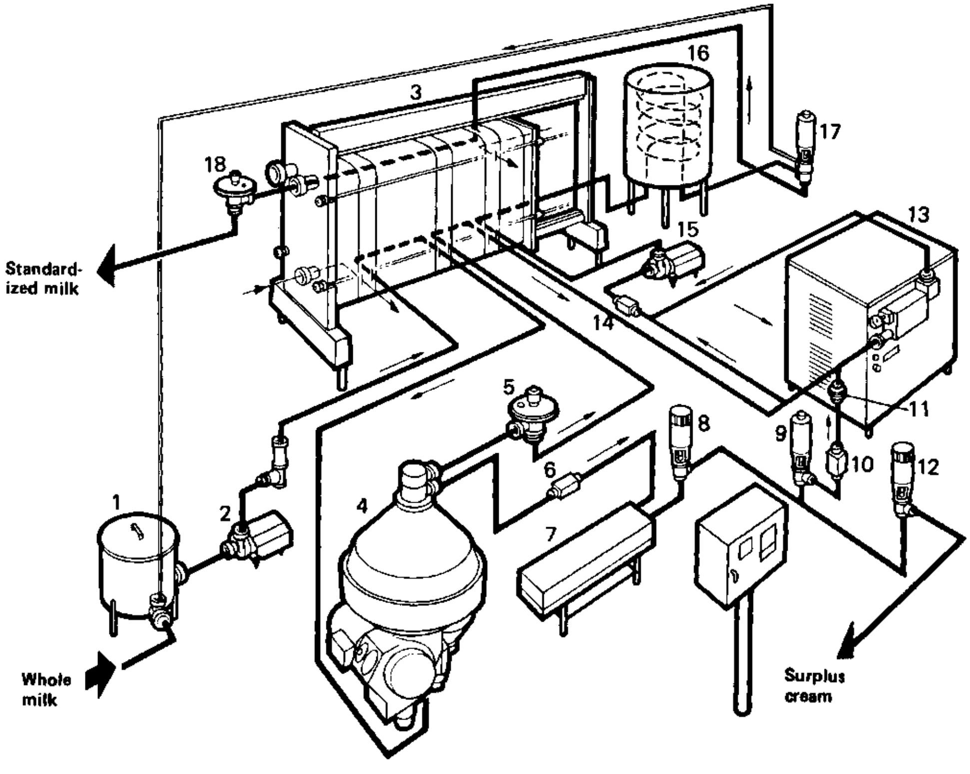

Fig. 23. Production line for market milk with partial homogenization. 1. Balance tank. 2. Product pump. 3. Pasteurizer. 4. Milk separator. 5. Constant-pressure valve. 6. Flow transmitter for cream. 7. Density transmitter for cream. 8. Regulating valve. 9. Regulating valve. 10. Flow transmitter for cream. 11. Check valve. 12. Cream valve. 13. Homogenizer. 14. Flow transmitter for standardized milk. 15. Booster pump. 16. External holding tube. 17. Flow diversion valve. 18. Constant-pressure valve. Courtesy: Alfa Laval AB.

have no separate clarifiers, but depend on the cream separator for the removal of extraneous matter (see Figure 24).

5.3.2 Cream separation

Because of the difference in density between milk-fat globules (lower than 1) and skimmed milk (higher than 1), the globules rise in milk under gravity, and slowly accumulate at the top where they form a cream layer. The rate of formation of this layer mainly depends on:

– *Size of the fat globules.* Larger globules rise quicker than smaller ones. The velocity of rising is proportional to the square of the diameter of the globules.

– *Availability of an agglutinating agent.* If such an agent is available on the surface of the fat globules, these globules will cluster. The clusters behave like big fat globules, which will rise much quicker than the individual ones. This phenomenon is responsible for a very quick formation of a cream layer in the cold in a very short period of time. Under favourable conditions a distinct cream line can be formed in cow's milk in one or two hours. Agglutinin – the agglutinating agent – is present in solution in cow's milk. At temperatures below 37 °C it precipitates on the surface of the fat globules; the lower the temperature, the more it precipitates. Consequently, cow's milk creams faster at lower temperatures. Neither buffalo's, goat's or ewe's milk contains the agglutinating agent. Buffalo's milk, having large fat globules, has fair creaming properties, particularly at high temperatures; but it creams much more slowly than cow's milk, especially if the milk has been cooled before creaming. The creaming properties of ewe's milk are much poorer than those of cow's milk, whereas goat's milk, having the smallest fat globules, hardly creams at all. Therefore, it is unpractical to obtain cream by allowing goat's milk to stand.

– *Temperature of the milk.* Cooling warm cow's milk before it is set for creaming stimulates the formation of clusters, as explained above. In buffalo's milk, creaming will be somewhat quicker if the milk fat is still liquid, i.e. is at temperatures above the melting range (Section 2.2), because in this case the difference in density between fat and plasma is greater; moreover, at higher temperatures the milk plasma is significantly less viscous and therefore creaming is quicker.

– *Heat treatment the milk has undergone.* Exposing milk to higher temperatures for longer periods than those applied in normal HTST pasteurization will increasingly damage the creaming properties of cow's milk, because of the denaturation of the agglutinin.

On some markets, a cream layer or cream line is an important selling point and the processing of milk is directed towards the maintenance or the improvement of the creaming properties of the milk. Many bacteria find their way to the cream line as a result of the agglutination process. This is often believed to result in non-homogenized milk having a better keeping quality than homogenized milk.

At farm level or in small dairy plants, the natural formation of a cream layer may be exploited to gather the cream for butter or ghee making, whilst the remaining low-fat milk (containing about 1% of fat) can be used for direct sales to consumers or for the manufacture of various products. Unfortunately, the bacterial quality of the milk may deteriorate during creaming if the milk is not properly cooled.

Dairy plants may cool the evening milk to store it for creaming. The next morning the cream is taken off and the low-fat milk is mixed with the fresh morning milk for processing. The quantity and the fat content of the cream that is obtained greatly depends on two factors: the fat content and properties of the milk, and the conditions under which natural or gravity separation takes place. The fat content of the cream usually varies between 20 and 25%.

Cream separators enable almost complete separation of fat globules. This allows for the production of cream with much higher fat contents, e.g. cream that meets the standard for whipping cream (minimum fat content 36%) and heavy creams with a fat content of 60% and more.

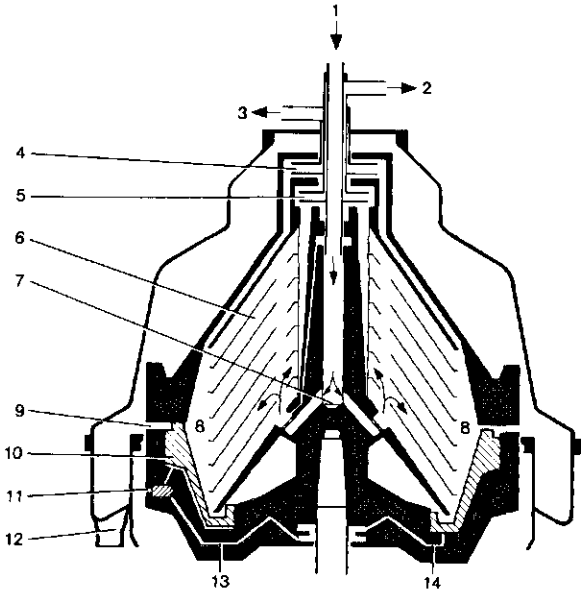

Fig. 24. Milk separator with self-cleaning bowl. Milk is fed into the separator (1) and led into the bowl (inlet 7), where it is separated into skimmed milk and cream in the disc set (6) (only a few discs are shown in the diagram). The skimmed milk flows outwards and is discharged by means of a centripetal pump (4) through outlet 3. The cream flows inwards and is discharged by pump 5 through outlet 2. Sludge is collected in holding space 8, from where it is automatically discharged through opening 9 at predetermined intervals. On the right side of the drawing the desludging outlet is shown in the open position; on the left side it is shown in the closed position. The vertically movable bottom (10) of the bowl controls the opening and closure of the desludging openings. The position of the movable bottom is controlled by water pressure in water ducts (13, 14) and piston valve (11). The sludge is carried off through outlet 12.
The operation of separators with a solid-wall bowl (no automatic desludging device) has to be stopped to allow for the manual removal of the sludge. Courtesy: Westfalia Separator AG.

Cream separators consist of a large number of closely packed conical plates (discs) in a bowl, which revolve at high speed (about 6000 rpm) (Figure 24). Milk is introduced between the discs through openings in the plates, the openings forming vertical channels. As a result of the high centrifugal force, the heavier fraction of the milk (the skimmed milk) moves outwards and the lighter fraction of the milk (the cream) moves inwards, that is to the centre of the bowl. Skimmed milk and cream are continuously discharged from the place where they are collected in the bowl. Because the distance between the discs is small (0.4 to 0.5 mm), separation takes less than one second. Special arrangements (regulating screws in the cream and skimmed milk discharge) enable the percentage of cream, and thereby the fat content to be controlled.

The centrifugal force exercised on the milk is converted into pressure, with the result that the separator may also function as a milk pump, forcing the skimmed milk (and mostly the cream) through pasteurizers, etc. to storage tanks, providing the back pres-

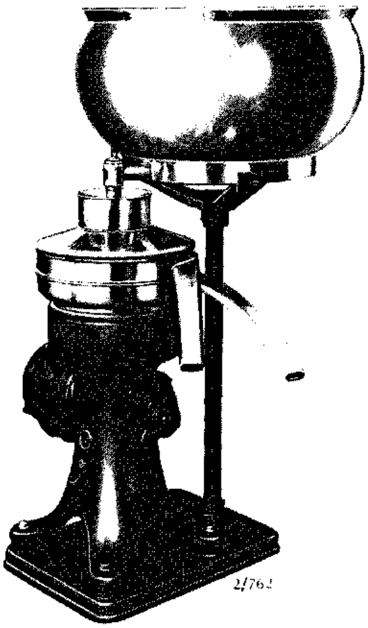

Fig. 25. Milk separator (small capacity) with free discharge of cream and skimmed milk. Courtesy: Westfalia Separator AG.

sure is not too high. Only small-capacity separators have free discharge for cream and skimmed milk (Figure 25).

Impurities in the fresh milk are flung outwards and form a sludge layer against the wall of the bowl. During operation the quantity of sludge grows until it disturbs the efficiency of operation. At that moment the separator has to be stopped and cleaned. Self-cleaning or desludging separators and clarifiers that push out the collected sludge at intervals enable continuous operation. However, they are only available for large capacities. Milk with an increased acidity produces much sludge with a high casein content. If the acidity is too high, sludge may even be deposited between the discs, greatly hampering efficient separation. The sludge has a high protein content and is sometimes used as animal feed. It is advisable to sterilize or to destroy it, because many bacteria and spores are collected in the sludge. Sludge from raw milk may contain pathogenic bacteria and is therefore a health hazard to animals.

The ideal temperature for separating milk by centrifugal force is about 40 to 60 °C. When cold milk is separated, more fat will be lost with the skimmed milk. However, special cold-milk separators that are quite efficient have been developed.

Separators are constructed in a wide range of capacities. Manually operated separators are available for farm use.

Clarifiers are very similar to cream separators (see Section 5.3.1). The main differences are:

- the discs are thicker, have no perforations and have a smaller diameter;
- milk is introduced near the outside of the bowl and leaves the bowl at the centre, without being separated;
- the distance between the discs is larger;
- the capacity is larger;
- there is more space for the collection of sludge.

5.3.3 Homogenization

The main characteristic of the homogenization process is the breaking up of the fat globules in a homogenizer, thereby reducing their average size to 1 μm and less, thus preventing the globules from rising during storage and forming a cream layer.

The most essential parts of the homogenizer are the homogenizing valve seat and plug (Figure 26). A clearance between the two is maintained hydraulically or by a spring. A number of reciprocating piston pumps (three or five) force the milk through the clearance at a pressure up to 250 atm, which results in the fat globules breaking up.

Since milk fat must be in a liquid state to be homogenized, the product that enters the homogenizer should be at a temperature of at least 40 °C.

As a result of the reduction of the size of the fat globules, the surface area of fat increases enormously, and new fat-globule membranes are formed, mainly by the absorption of casein on the globule surface. The presence of casein on the surface of the globules makes them behave differently; they behave very similar to large casein micella. Consequently, sour milk products and cheese manufactured from homogenized milk have different rheological properties. Moreover, the fat content in

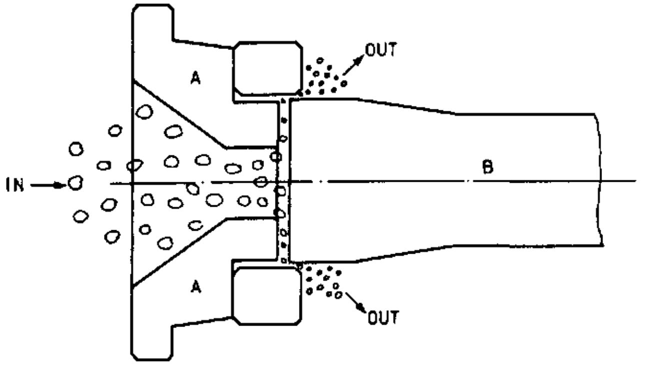

Fig. 26. Homogenizing valve. Milk enters the valve through the centre bore of the valve seat (A) and is forced through the narrow opening (clearance) between the valve seat and the valve plug (B), thus breaking up the fat globules. Courtesy: Maskinfabriken Rannie AS.

the whey obtained if cheese is made from homogenized milk is lower, but, unlike whey from normal milk, no whey cream can be separated in a separator.

Immediately after homogenization, new globule surfaces must be formed. At this moment a casein micelle may become attached to two globules at the same time. In this way, clusters of small fat globules are formed. They can be dispersed by the application of a turbulent force, that is by a second homogenization at a much lower pressure. Special two-stage homogenizers can be used for this purpose. Clusters will not be formed in normal milk, only in cream with a fat content of at least 9%. The higher the fat content, the greater the risk of clustering. In cream with a fat content of 15% and higher, clustering can hardly be avoided.

Separating milk, homogenizing the cream in a one-stage homogenizer to enhance clustering and mixing the skimmed milk again with the homogenized cream, allows for the formation of a heavy cream line. This milk is called viscolized milk.

When raw milk is homogenized, rancid flavours develop. Since the defective flavour is already noticeable after a few minutes, raw milk must be heat-treated immediately after homogenization. Heat treatment prior to homogenization is to be preferred, but the sanitization programme should be very effective to prevent recontamination of the milk in the homogenizer.

It is impossible to separate homogenized milk with ordinary cream separators.

Homogenized cream cannot be churned to butter; the foaming properties of homogenized whipped cream are poor or non-existant.

Homogenized milk is easier to digest, particularly for infants. The heat stability is diminished in the manufacture of condensed milk. In-bottle sterilized milk must be homogenized, to prevent the formation of a cream plug that can no longer be dispersed in the milk.

5.3.4 Standardization

To guarantee the consumer a product of constant fat content and to meet national and international standards, the fat content of milk destined for the manufacture of various milk products is standardized. The manufacture of products with a higher fat content than the officially or generally accepted standards will give financial losses.

In most cases, the fat content of the raw milk is higher than the required standard, and standardization of the milk can be accomplished by:

– Mixing whole milk with partly or totally skimmed milk, or by mixing skimmed milk with cream. This is called indirect standardization.

– Separating whole milk to achieve the required fat content. This is called direct standardization.

In small-scale operation the costs of standardization may be higher than the profits, especially if no profitable commercialization of the cream is possible.

Under normal conditions, the solids-non-fat content of the milk is high enough to meet official standards – if any – for fluid milk and fluid milk products. The addition of water to bring down the solids-non-fat content is usually considered to be an adulteration, even if the lowered solids-non-fat content will still meet the legal standards.

Standards for other products like cheese, condensed milk and milk powder include a fat component and a solids (or a solids-non-fat) component. In this case, standardization is more complicated, because a certain ratio of fat to solids-non-fat has to be taken into consideration.

Indirect standardization by mixing

The quantity of skimmed milk to be added to whole milk to obtain standardized milk with a certain fat content can easily be found by making use of the 'mixing square' (Figure 27). The square shows:

H = fat content of the milk with the highest fat content (e.g. whole milk with 5% fat)

L = fat content of the milk with the lowest fat content (e.g. skimmed milk with 0.05% fat)

S = fat content of the standardized milk to be produced (e.g. 3% fat)

QH = quantity of milk available with highest fat content, that is milk to be standardized

QL = quantity of milk with lowest fat content; to be mixed with milk with highest fat content.

In the example, $H - S = QL = 5 - 3 = 2$, and $S - L = QH = 3 - 0.05 = 2.95$, which means that for every 2.95 kg of whole milk 2 kg of skimmed milk has to be added to obtain standardized milk with 3% of fat; in this case that is 4.95 kg of standardized milk.

It is, of course, also possible to use formulae, viz.:

$$100 \times S = QH \times H + (100 - QH) \times L, \text{ and}$$

$$QH + QL = 100$$

In these formulae the same symbols are used as in the mixing square, but in this case

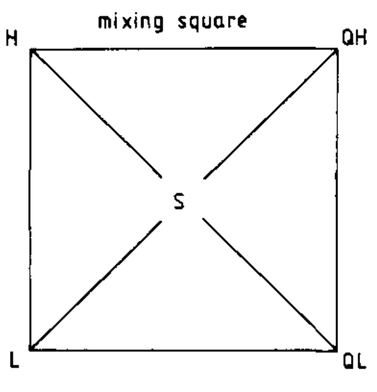

Fig. 27. Mixing square. For explanation of H, L, S, QH and QL see text.

QL stands for the quantity of low-fat milk that has to be added to *QH* kg of high-fat milk to obtain 100 kg of standardized milk. If cream and skimmed milk are mixed to obtain standardized milk, *QH* and *H* represent the quantity of cream and its fat content.

To bring the fat content of whole milk down to the required fat content, a sufficient quantity of pasteurized skimmed milk (from the previous day or just produced) must be available. The whole milk (or cream) can be pumped into a standardizing tank containing skimmed milk, or the skimmed milk can be added to a tank with the full-cream milk or cream. In either case the liquid should be thoroughly mixed by stirring. The fat content of the mixture should be checked and if necessary adjusted by adding more skimmed milk or cream. The main problem of this system of standardization is the accurate measurement of the quantities of milk or cream. If cream is to be added, it may be difficult to obtain a homogeneous dispersion of the fat in the milk.

Mixtures of raw and pasteurized milk should be pasteurized as quickly as possible, to avoid lipolysis.

Direct standardization

Direct standardization is possible by returning part of the cream to the skimmed milk after the liquids have been discharged from the separator. For this purpose, a special connection with a standardization valve has to be fitted between the discharge pipelines of cream and skimmed milk.

5.3.5 Centrifugal homogenization and removal of bacteria

A special application of the centrifugal force is found in homogenization and the removal of bacteria.

Centrifugal homogenization

In a specially designed centrifuge, whole milk is separated into milk containing only the smaller fat globules, and a rather heavy cream with the larger fat globules. The milk leaves the centrifuge in the same way as the skimmed milk leaves a normal separator. The heavy cream with the larger fat globules passes through a special homogenizing device, in which fat globules are broken up. Thereafter, the cream is fed back into the whole milk entering the bowl, so that it passes through the centrifuge again. The fat globules that have been sufficiently broken down now leave the centrifuge with the milk. Some of the fat globules recirculate several times through the bowl, until they are sufficiently broken up. A few minutes after the operation has started, an equilibrium is reached, and milk leaving the centrifuge has the same fat content as the milk entering it, but the size of the fat globules has been reduced.

Centrifugal removal of bacteria

Special types of clarifiers (Figure 28) have been designed for the continuous removal of micro-organisms and spores. They have a few small holes in the bowl for the con-

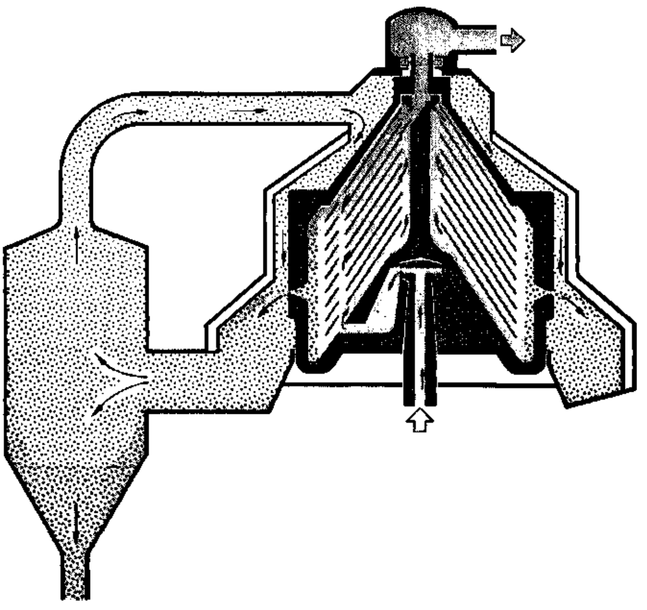

Fig. 28. Centrifuge for removal of micro-organisms (Bactofuge; Alfa Laval AB). Milk is fed into the bowl through a stationary pipe in the bottom of the centrifuge, where it is forced through the revolving discs. A concentrate, which contains about 90% of all micro-organisms, but also protein, lactose and other milk constituents, is continuously ejected and discharged through openings in the wall of the bowl. The concentrate, which amounts to no more than 3% of the milk fed into the bowl, is recoverable. It has a foam-like consistency and is collected in the cover surrounding the bowl, where it is de-aerated. The air is recirculated through the bowl cover, whilst the concentrate is drained off from the bottom of the cyclone.

tinuous discharge of a small quantity of skimmed milk containing about 90% of the micro-flora. Two of these clarifiers operating in series will reduce the bacterial count of milk by about 99%. The separated skimmed milk may with micro-organisms and spores be used after sterilization at high temperatures.

Centrifugal removal of bacteria cannot replace heat treatment of milk; for instance, it does not guarantee that all pathogens will be removed. It must be considered as an additional technique for a further reduction of the amount of micro-organisms and, which may be of special interest, the number of spores. It has proved its value in the removal of *Clostridium* spores, notably from cheese milk (Chapter 9).

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5.4 Manufacture of reconstituted and recombined products

Milk powder and milk fat (butter fat) may play an important part in the production of liquid milk and milk products in areas where milk production is impossible, or where seasonal or permanent shortages occur. There are several ways of using milk powder and milk fat in the manufacture of reconstituted, recombined or toned milk.

5.4.1 Reconstituted milk

Reconstituted milk is the product obtained by 'dissolving' milk powder in water. The product thus obtained will have the same composition as the milk used for the production of the powder, provided that the correct quantities of water and powder are mixed. Examples are skimmed milk and full-cream milk.

Skimmed milk
If it is assumed that the reconstituted skimmed milk must have a solids content of 9%, 9 kg of skimmed milk powder must be mixed with 100 − 9 = 91 kg of water to obtain 100 kg of the reconstituted product, if the water content of the powder is ignored. Taking the water content into account, the quantities of milk powder and water to be mixed to obtain 100 kg of skimmed milk can be calculated with the formula:

$$P = \frac{100 \times SNF}{100 - H} \tag{1}$$

$$W = 100 - P \tag{2}$$

where:
P = kg of milk powder
SNF = percentage of SNF in reconstituted milk
H = percentage of water in milk powder
W = kg of water

Full-cream milk
If it is assumed that the reconstituted milk should have a fat content of 3.2% and the milk powder has a fat content of 26%, 26/3.2 = 8.125 kg of milk powder must be mixed with 100 − 8.125 kg of water to obtain 100 kg of full-cream milk. The quantities to be mixed can also be calculated with the formula:

$$P = \frac{F_p}{F} \tag{3}$$

$$W = 100 - P \tag{4}$$

where:
F = fat content reconstituted milk
F_p = fat content milk powder

5.4.2 *Recombined milk*

Pure milk fat can be added to reconstituted skimmed milk to obtain full-cream milk (called recombined milk). If it is assumed that the recombined milk must have a fat content of 3% and an SNF content of 9%, 3 kg of pure milk fat must be mixed with 9 kg of skimmed milk powder and 100 − 3 − 9 = 88 kg of water, if the water content of the powder is ignored. Taking the water content into consideration, the quantities of milk fat, skimmed milk powder and water to be mixed to obtain 100 kg of recombined milk can be calculated with the formula:

$$P = \frac{100 \times SNF}{100 - H} \tag{5}$$

$$M = F \tag{6}$$

$$W = 100 - P - M \tag{7}$$

where:
M = kg of pure milk fat
F = percentage of fat in recombined milk
SNF = percentage of SNF in recombined milk

In this case, the fat content of the skimmed milk (less than 1%) is still ignored.

5.4.3 *Toned milk*

Usually, milk is standardized to a certain fat content for the manufacture of liquid milk. In the event of milk shortages, fresh milk with a high fat content can be standardized by the addition of reconstituted skimmed milk to obtain the required fat content. The 'mixing square' (Section 5.3) can be used to calculate the quantities to be mixed. The product thus obtained is called toned milk. If the fat content of the raw milk is high, for instance in buffalo's milk, considerable quantities of skimmed milk powder can be used.

Double-toned milk. For human nutrition, the proteins are often considered to be the most valuable part of milk. The price of reconstituted skimmed milk is comparatively low, especially compared with the price of locally produced milk. For these reasons, a cheap, high-protein product is produced in a number of countries by mixing the local product with reconstituted skimmed milk in such a way that the resulting product has a low fat content, e.g. 2%, but an increased SNF content, e.g. 10%.

The quantities of full-cream milk, skimmed milk powder and water that have to be mixed to obtain 100 kg of double-toned milk can be calculated with the formula:

$$R = \frac{F_t}{F_p} \times 100 \tag{8}$$

$$P = (SNF_t - \frac{F_t}{F_p} \times SNF_p) \times \frac{100}{100 - H} \tag{9}$$

$$W = 100 - R - P \tag{10}$$

where:

R = kg of full-cream milk
P = kg of skimmed milk powder
F_t = percentage of fat in toned milk
SNF_t = percentage of *SNF* in toned milk
F_p = percentage of fat in full-cream fresh milk
SNF_p = percentage of *SNF* in full-cream fresh milk

5.4.4 Raw materials and water

Raw materials. Any slight defects in the flavour of the milk powder and the milk fat will be noticeable in the reconstituted or recombined product. Therefore, the quality of the powder and the milk fat must be very high (Sections 8.8, 10.2). Milk fat of sufficiently high quality to be used for recombining is known as anhydrous milk fat. International standards for these products have been set by FAO/WHO.

For the production of some recombined products a small part of the skimmed milk powder is replaced by sweet-cream buttermilk. In this case, only a high-grade product should be used. Neutralized sour-cream buttermilk is unfit for use in recombining. The product must be completely soluble and may not show any sign of oxidation defects. Buttermilk powder may have a fat content up to 10%. This must be taken into account when calculating the quantities of the various ingredients that must be mixed in recombining and toning.

Water. Although the reconstituted and recombined products are usually pasteurized or sterilized, water of high bacteriological quality should be used. Moreover, this water must be free from sediment and may not have off-flavours. Hard water (more than 150 to 200 ppm; Section 4.2) makes it difficult to obtain an adequate dispersion of the milk powder. An abnormal pH, and high calcium and magnesium contents adversely affect the heat stability of reconstituted and recombined products. This is especially important for the manufacture of recombined evaporated milk.

5.4.5 The reconstitution process

Milk powder does not reconstitute easily. The three main problems that will be encountered are the formation of lumps, incomplete solubility, and the formation of dust.

Formation of milk-powder lumps
Since milk powder has a low density (about 0.5) and a high hygroscopy, it tends to float on water, forming lumps. A considerable mechanical force is required to mix water and powder and to allow the latter to 'dissolve' completely. Generally, reconstitution is much easier at higher temperatures, e.g. 50 °C.

Incomplete solubility
The solubility of milk powder may be detrimentally affected in three ways:
- Destabilization of the powder during its manufacture. Excessive heat treatment of the milk during processing and long exposure of the powder to hot air in the drying chamber may result in a loss of solubility of the powder.
- Destabilization of the powder during storage. Absorption of water during storage may lead to destabilization and formation of insoluble – so-called Maillard – products.
- Reversible destabilization of the colloidal phosphate. During drying, the colloidal phosphate may destabilize; this is especially likely if milk is concentrated to very high solids contents before drying, and if drying takes place at very high temperatures. If the powder is dissolved in warm water (for instance, at a temperature of 45 to 50 °C), the colloidal phosphate is restored almost instantaneously and the process of complete reconstitution takes very little time. If reconstitution takes place at low temperatures, the milk should be kept sufficiently long for complete restoration of the colloidal phosphate and consequently for complete reconstitution. To avoid the development of micro-organisms the milk should be stored below 10 °C.

Formation of dust
Milk powder consists of very small and light particles, which may form considerable quantities of dust, especially when the powder is poured out of the containers (usually paper bags). To avoid milk powder settling in the processing area of the plant, thereby encouraging the development of moulds, it is advisable to empty the containers and to initiate the reconstitution process in rooms separate from the processing area. Full-cream milk powder is less dusty than skimmed milk powder.

5.4.6 Reconstitution systems

There are various systems for the reconstitution of milk powder, but principally two systems can be distinguished, namely:
- the batch system,
- the circulation system.

The first system is mainly used for small-scale operations, the second one for large-scale operations. Combinations of both systems are found.

Batch system

In the batch system, use is made of a mixing tank in which milk powder and water are mixed in dosed quantities. Such tanks are equipped with special rapid stirring devices. If the equipment is not properly designed, it is difficult to avoid the formation of persistent lumps. The application of an additional circulation system, in which a centrifugal pump disperses the lumps, considerably facilitates the dissolving process.

If only small quantities of milk powder are to be reconstituted, it is often advantageous to mix the powder with a small quantity of water until a homogeneous smooth mixture is obtained. Thereafter, this mixture can be diluted with water until the required composition is obtained.

Circulation system

In its simplest design, the system consists of a mixing tank and a circulation circuit including a centrifugal pump and a hopper (Figure 29). The latter is inserted into the pipeline of the circulation system at the suction side of the pump. The water for reconstitution is supplied to the tank and brought into circulation through the circuit. Then, the required quantity of milk powder is introduced into the system through the hopper. The water/powder mixture is thoroughly mixed by the rapid action of the centrifugal pump, which promotes quick dissolving of the powder. Circulation can be stopped as soon as all powder has been 'dissolved'.

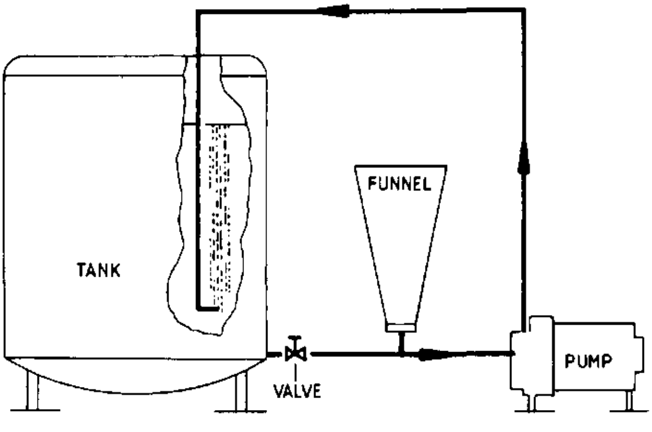

Fig. 29. Reconstitution of milk powder (circulation system; see text).

5.4.7 The recombining process

Recombined milk is generally produced by the emulsification of milk fat in reconstituted skimmed milk. The milk fat can be added immediately after the powder has been dissolved, but it may be recommendable to pass the liquid through a separator or a clarifier to remove all undissolved particles.

The fat must be melted before adding it to the reconstituted skimmed milk, for instance by storing the drums with the fat in a hot room at a temperature of 45 to 55 °C. Melting in steam chests, tunnels or on rotating heated platforms is another way of melting the fat. Temperatures over 50 °C are to be avoided, because of the risk of fat oxidation. Before mixing, the reconstituted skimmed milk should be warmed to the same temperature as the milk fat.

The same hopper that is used for adding the powder to the water can be used for the fat. The centrifugal pump disperses the fat through the milk, but concentrated mixtures that have a high viscosity, such as those used for the production of recombined concentrated milks or recombined milk powder, require a high-power mixing device. After a first dispersion is obtained with the centrifugal pump, a much finer distribution is required to obtain a stable emulsion. Therefore, the milk must pass through a homogenizer, where a pressure of 150 to 250 atm is applied. To avoid the risk of lowering the heat stability, lower pressures are advisable when producing concentrated recombined products.

Since the surface layers (membranes) of the fat globules are lost during the production of anhydrous milk fat, the recombined products will contain only small amounts of the emulsifying compounds normally present on the surface of the fat globules. If necessary, the stability of the product may be improved by replacing part of the skimmed milk powder (e.g. 10%) by sweet-cream buttermilk powder, which also gives the product a more creamy taste; high proportions of buttermilk powder may, however, cause oxidative off-flavours.

5.4.8 Recombined liquid milk and fermented milk products

Pasteurized liquid milk

Recombined milk should be pasteurized at the customary time-temperature combination, e.g. at 72 to 73 °C for 15 to 20 seconds. After pasteurization the milk must be cooled and packaged.

Usually, high temperatures are used in the manufacture of milk powder; this results in the powder having a distinctive flavour (very similar to cooked flavour). Very high temperatures are generally used in the production of full-cream milk powder, because this improves the keeping quality (Section 10.2). Such powder causes a distinct 'milk powder' flavour in reconstituted full-cream milk. The flavour resulting from high temperatures in the manufacture of milk powder will also be found in the recombined products, but will be hardly noticeable, if at all, if so-called low-heat milk powder is used. If high-quality (medium-heat) skimmed milk powder and high-quality anhydrous milk fat are used, liquid milk may contain up to about 60% recombined milk without any noticeable effect on the flavour of the product, especially not if part of the skimmed milk powder is replaced by high-quality sweet-cream buttermilk powder.

In areas where an intensive heat treatment is used in pasteurization and the consumers are used to cooked flavours, percentages of milk powder higher than 60% may be found quite acceptable.

Sterilized liquid milk
Recombined milk can be sterilized by heating the product in bottles or in tins at 120 °C for 10 to 15 minutes or at equivalent time-temperature combinations. As a result of the intensive heat treatment, the fat emulsion may destabilize and lumps of fat may be formed if the milk has not undergone a proper homogenization process.

UHT milk
Ultra-high temperature treatment of recombined milk in combination with aseptic packing does not meet with serious problems. Low-heat milk powder may give a better flavour, but medium-heat milk powder may be preferred, because the product will have a better heat stability. UHT milk may show gelation during storage, especially at comparatively high storage temperatures (e.g. over 25 °C). Enzymes present in the milk powder and originating from bacterial growth in the original, fresh milk may also induce gel formation (Section 6.5).

Recombined creams
The stability of the milk-fat emulsion causes the major problem in the production of recombined creams, especially if the fat content is high, like that of whipping cream, and the product is sterilized. High homogenization pressures may give rise to the formation of clusters of fat globules and may decrease the heat stability. On the other hand, low homogenization pressures may give rise to creaming and coalescence. The correct pressure must be found experimentally. Low-heat milk powders will usually give better results than medium-heat powders.

Fermented liquid milk products
There is no difference in technique between the production of fermented liquid milk products from fresh milk and from recombined milk. It is advisable to use medium- or even high-heat milk powder in the production of recombined yogurt and similar products, in order to boost the growth of starters and the product firmness.

5.4.9 Recombined concentrated and dried products

In many countries, recombining industries for the production of evaporated and sweetened condensed milk, and full-cream milk powder and other dried products, such as baby foods, have been established. These industries depend on the import of comparatively cheap skimmed milk powder and anhydrous butter fat. Contrary to the production of concentrated and dried products from fresh milk (Chapter 10) an evaporating plant is – strictly speaking – not required, because the milk solids and the water – and if necessary other products – can be mixed in a proportion identical to that of the final product or to that of the liquid product still to be dried.

A major problem in the production of the recombined condensed products is the proper control of the viscosity during processing as well as after prolonged storage. The most important factor for the control of the viscosity of condensed products manufactured from fresh milk is its heat treatment before condensing starts (Section 10.1). The processing technique applied in the production of commercially bought milk powders is rarely known, but it is obvious that the heat treatment applied in the production of these powders may often differ from that required in the production of recombined products. The estimation of the WPN value (Whey Protein Nitrogen index – see Section 10.2) may give some indication for adjustments of the processing technique, but in general it is advisable to buy the milk powders on specification.

Evaporated milk
This product may not develop too high a viscosity and must not coagulate during sterilization. Consequently, milk powders with a high heat stability, i.e. milk powders that give a reconstituted milk product of good heat stability are most suitable for the production of recombined evaporated milk. On the other hand, the recombined product should not be too thin, lest consumers think that it lacks richness. Milk powders with a low WPN value are to be preferred.

The risk of a very high viscosity increases with the rise of the solids content, particularly the protein content of the product. Thus, more problems will be encountered if evaporated milk has to meet the British standard (31% solids) than if it has to meet the US standard (26% solids).

Replacing 10% of the milk powder by sweet-cream buttermilk powder may increase the heat stability of the product, but may unfavourably affect the stability of the fat emulsion.

In the production process, the raw materials are mixed with water in a proportion that allows for a slightly higher solids content than the final requirement. In a later stage of processing the product will be standardized. After the recombination procedure has been completed, the subsequent processing procedures may differ, but in general the product is filtered, de-aerated, homogenized, cooled and pumped to a standardizing tank, where stabilizers, mainly phosphates, can be added and the product is brought to the required composition. Unduly delaying the successive stages of processing is not good practice: it will promote bacterial development and may adversely affect the stability of the product against age-thickening and gel formation. After canning, the product is sterilized, either in batches or in continuous operation.

The cream may separate, causing serious problems. This must be prevented by proper homogenization procedures. Homogenization should on the one hand be sufficiently intensive to allow for a fine dispersion of the milk fat, but on the other hand the adverse effect of homogenization on the heat stability of the product should be taken into account. Some measures that are recommended to improve stability, such as two-stage homogenization and the use of emulsifiers, are of dubious efficacy.

The recombined product may to some extent lack the full flavour of freshly evaporated milk, because of the absence of most of the phospholipids. Incorporating sweet-cream buttermilk powder in the mixture will considerably increase its phospholipid content, thus contributing to the taste of the product.

See also Section 10.1 on concentrated products.

Sweetened condensed milk

The very high solids content of condensed milk (31% milk solids and 43.5% sucrose) requires special recombining (milk solids) and dissolving (sugar) techniques. The common approach consists of reconstituting the skimmed milk powder in water, followed by dissolving the sugar and then finally adding the fat. It is easier to dissolve the sugar in the reconstituted skimmed milk than in the recombined product. The latter procedure will not give a smooth product. A little fat added in the early stages of mixing will limit excessive foaming of the product, but the addition of too much fat at this stage may cause a stable foam to form. Sometimes, the fat is added in the form of a separately prepared homogenized cream. It is claimed that this procedure facilitates the control of the stability of the fat dispersion in the final product.

After the ingredients have been 'dissolved' and the mixture is completed, the recombined condensed milk should be filtered, de-aerated and subsequently homogenized at a low pressure (about 60 to 70 atm) before the mixture is pasteurized at about 80 °C for 30 seconds. Thereafter, the milk is cooled, provided with 'seed lactose' to control milk sugar crystallization, and packaged.

The control of the viscosity during storage is one of the major problems for the manufacturer. It is important to select the right type of skimmed milk powder (usually with a low WPN value) or to order it on specification.

See also Section 10.1 on concentrated products.

Recombined full-cream milk powder

Recombined spray-dried full-cream milk powder is manufactured by spray-drying a recombined mixture containing 43 to 48% solids content (the lower contents for nozzle-atomizers, the higher contents for disc-atomizers). Owing to the high solids content of the mixture, much attention must be paid to the control of its viscosity and stability before drying.

A typical mixture to produce milk powder with a fat content of 26% could be:
- 3250 kg of skimmed milk powder,
- 325 kg of buttermilk powder,
- 1250 kg of anhydrous milk fat, and
- 5175 kg of water.

After the milk fat has been dispersed into the reconstituted skimmed milk and the mixture has been de-aerated it will pass through a homogenizer at low pressure. It is advisable to HTST pasteurize and consequently to dry the mixture immediately after homogenization. High homogenization pressures and temperatures (higher than 100 atm and 60 °C), and prolonged storage of the mixture, especially at increased temperatures, may cause considerable increases in viscosity, making the product unfit for spray-drying.

See also Section 10.2 on dried products.

Filled recombined products

In a number of cases, recombined 'milk' is produced by using vegetable oils instead of milk fat. The names of such imitation products generally include the adjective 'filled' instead of the adjective 'recombined'. Well-known products are filled sweetened condensed milk and filled evaporated milk.

Coconut oil is mainly used for filling, but mixtures with other vegetable oils are sometimes preferred, especially to compensate for the low content of essential polyunsaturated fatty acids in coconut oil. Replacing 10% of the coconut oil by maize oil, which has a high content of polyunsaturated fatty acids such as linoleic acid, may overcome objections to using the product for infant food. Extra vitamins may also be added.

The vegetable oils should be of very high quality and flavourless grade. Unsatisfactory refined oils may give the product a 'vegetable taste'.

Recombined butter

Recombined butter is produced in a number of tropical countries. Its specific advantages are:

- comparably cheap and durable basic materials (anhydrous milk fat and skimmed milk powder can be used);
- a constant quality can be maintained;
- the production is independent of the availability of local fresh milk and can easily be adjusted to the demand instead of controlling the distribution by cold-storage stocks of fresh butter.

In fact, these arguments are applicable to all recombined products.

To meet the internationally accepted standard of a minimum fat content of 80% and a maximum water content of 16%, a mixture of the following composition can be used:

- 80.0% anhydrous milk fat,
- 2.5% skimmed milk powder,
- 1.5% salt, and
- 16.0% water.

In general, it may not be advisable to work 'on the razor's edge' and 0.1 to 0.2% more milk fat and less water may be applied.

In the first phase of manufacture, milk powder, salt and water are mixed thoroughly at a temperature of 45 to 50 °C, making sure that all the milk powder is completely reconstituted. Thereafter, the liquid is well mixed with the melted butter at the same temperature. In the second phase of manufacture, the crystallization of the milk fat must be initiated and the aqueous phase must be distributed through the fat in the form of very small droplets, ensuring a fine dispersion of the aqueous phase. At the same time, the product should obtain the required 'butter texture', that is to say, the basis for such a texture should be laid. This is achieved by first passing the mixture under high pressure through a votator, that is a 'scraped-surface heat exchanger', where the mixture is rapidly cooled to a temperature of about 10 °C, and thereafter through a continuous butter worker, where the butter is thoroughly worked. In the heat exchanger, crystallization of the fat is initiated, but total crystallization and acquisition of the final texture are obtained after the product has left the butter worker, i.e. has been packaged. Recycling part of the butter through the votator will promote crystallization and improve the texture of the butter.

Attempts to produce cultured recombined butter by using starters instead of reconstituted milk powder for mixing with the butter have not been very successful. Since the bland taste is not appreciated by many consumers, artificially cultured recombined butter is made by adding lactic acid and flavouring compounds, such as diacetyl, to the aqueous phase. Recombined butters are more susceptible to oiling-off then freshly churned butters. Recombined butter can also be manufactured by churning recombined cream. Intensive homogenization of the cream will hamper the churning process.

See also Sections 8.1-8.4 on butter.

Ghee

Ghee can be produced from anhydrous butterfat by melting the fat and 'solidifying' it again in a way that allows large crystals embedded in liquid milk fat to form. To meet local demand, flavouring agents may be added.

See also Sections 8.6 and 8.7 on ghee.

Cheese

It is not difficult to produce acid-coagulated cheese from recombined milk. Rennet-coagulated cheese, however, is the most difficult product to make from recombined milk – particularly cheeses that require ripening – because the rennetability and synereses of the milk and curd are reduced. Changes in the colloidal characteristics of the casein complex and destabilization of the whey proteins are responsible for differences during processing and ripening, even if the powder shows an excellent solubility index.

The main differences between using recombined and fresh milk for making cheese are:

– a poorer rennetability,
– a poorer expulsion of the whey,
– a different, generally poorer, ripening.

Although medium-heat milk powders may be used for the production of a number of fresh cheeses, provided the processing techniques are properly modified, low-heat milk powder is preferable. As a matter of fact, this type of powder is the only one suitable for the production of cheeses that require extended ripening periods. For the production of this type of cheese, only a minor part of the fresh milk should be replaced by reconstituted or recombined milk.

In general, the curd produced from reconstituted and recombined milk loses less whey. The milk will coagulate in the form of a softer gel. The normal increase of firmness of the gel resulting from the expulsion of whey must be promoted by specially modifying the normal cheese-making procedure. Such modifications are:

– Using special starters containing streptococci that bring about fast and full acid and flavour development. Some raw-milk cheeses are normally produced without the addition of a starter, because the raw milk already contains sufficient numbers of lactic acid bacteria. If reconstituted milk is substituted for the fresh milk, a starter must be added, because milk powder – and also the reconstituted milk – contains only small numbers of bacteria and, in general, no lactic acid bacteria.

– Addition of increased quantities of rennet to shorten the clotting time and to increase the firmness of the curd.

– Addition of an extra quantity of calcium chloride, e.g. 20-50 g per 100 l milk, depending on the cheese variety. The calcium chloride will improve the rennetability and syneresis.

– Using higher temperatures, especially during the working and washing of the curd. The working period may be extended.

Cheeses produced from curd with a poor whey expulsion may develop a sour taste and a crumbly texture. However, if – with a modified technique – a normal expulsion of whey is achieved, the hard and semi-hard cheeses may show a rubbery texture, whilst the flavour associated with fresh-milk cheeses may be lacking or may not develop sufficiently. Such cheeses can successfully be used as a substitute for fresh-milk cheeses in the production of processed cheese.

See also Chapter 9 on cheese.

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6 Heat treatment of milk and processing of liquid milk

6.1 Objectives of heat treatment

Heat treatment is applied to milk with the following objectives:
- to kill all bacteria and viruses that may be harmful to health;
- to kill other micro-organisms (and their possible spores) especially those that can cause spoilage of milk and milk products;
- to inactivate milk enzymes and enzymes produced by micro-organisms;
- to affect the milk's physical and chemical properties in order to improve its suitability for further processing.

The achievement of these objectives mainly depends on the temperature and time (duration) of heat treatment; in other words on the time-temperature relationship. The time required to obtain the same effect of bacteria killing and enzyme denaturation decreases progressively with increased temperature (Figure 30).

Sometimes, heat treatment to temperatures below 100 °C is designated pasteurization, and that to temperatures above 100 °C sterilization. This does not give a practical distinction between the two systems of heat treatment, especially not if the term 'sterilization' is confused with 'sterile'. Milk heated to temperatures above 100 °C may – depending on the intensity of the treatment – still contain microbes, or at least spores of certain species that have survived the 'sterilization' process. The term 'pasteurization' should therefore be reserved for all processes that kill the pathogens (micro-organisms and viruses) and a comparatively large number of other micro-organisms, whilst the term 'sterilization' should only be used for all processes that kill all micro-organisms, spores and viruses (but see Section 6.5). Products that are properly sterilized only deserve the name 'sterile' or 'sterilized' if they do not contain micro-organisms, viruses and spores, that is if they have not been recontaminated after sterilization.

Some products do not endure the intensive heat-treatment required for complete sterilization, because their characteristics will be changed too much. In such cases a more moderate treatment may be practised, which destroys pathogens and so many other micro-organisms that a prolonged keeping quality is guaranteed. Such products are sometimes indicated 'commercially sterile', in which case a prescription of the conditions of storage and the ultimate date of consumption should be mentioned on the label of the container.

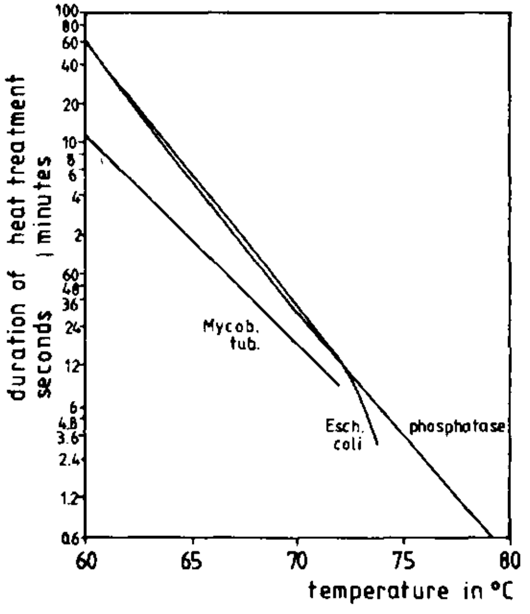

Fig. 30. The resistance of phosphatase and coli and tubercle bacteria to various heat treatments.

In the manufacture of some products, the choice of the intensity of heat treatment also depends on what physical properties are required for a given product (Sections 7.3 and 10.1), or on the keeping quality of that product.

Killing of pathogenic bacteria. All common pathogenic micro-organisms and viruses that are likely to occur in milk are destroyed at temperature-time combinations that are less intensive than those required to kill coliforms and to destroy alkaline phosphatase (Figure 30). This means that combinations equal to or more intensive than those in Figure 30 will make milk safe for consumption, provided recontamination is avoided.

Killing of non-pathogenic bacteria. The rate of destruction of micro-organisms depends on their characteristics of heat-resistance and the temperature-time combination of heat treatment (Section 2.4). Whilst the destruction of mesophilic bacteria and of moulds and yeast generally starts at a temperature around 60 °C, thermophilic and thermoresistant bacteria are only destroyed at higher temperatures. The most resistant are the spore-forming bacteria: their vegetative cells can be killed by pasteurization, whereas the spores require more intensive time-temperature combinations for complete destruction, e.g. 120 °C for 15 minutes or more.

6.2 Systems of heat treatment

Two basic systems for heat treatment can be distinguished:
- the holder system,
- the continuous-flow system.

With both systems, milk can be pasteurized as well as sterilized.

To control the results of the heat treatment it is necessary to cool the milk as quickly as possible immediately after heating. Slow cooling may give rise to heat damage or accelerate the growth of bacteria that survived pasteurization.

6.2.1 Holder systems

With these systems, milk is either heated in a vat and then packaged, or it is first packaged and then heated. The methods are referred to as 'vat pasteurization' and 'in-package pasteurization' (or sterilization), respectively.

6.2.1.1 Vat pasteurization

This system is well suited for small-scale operation, for instance for operations where less than 3000 to 5000 l of milk are available. Although it is possible to sterilize milk under pressure in hermetically sealed vats, the vat or batch system is used solely for pasteurization.

The vat pasteurizer may be rectangular, but a vertical, cylindrical design is preferred, for practical reasons. The vat normally consists of an inner vessel, surrounded by an insulated outer casting, thus forming a jacket, through which hot water or steam is passed (Figure 31). After the milk has reached the required temperature it is usually held at that temperature for a certain period. Thereafter, it is cooled as quickly as possible, by circulating a refrigerant through the jacket.

Vat pasteurizers have a small heating surface relative to their contents. Heat transfer is greatly improved by agitating the milk. Agitators of different design are used for this purpose. They may even consist of double-walled paddles or other devices with internal steam or water circulation.

Care must be taken to avoid foam formation while the vat is filling, because it is very difficult to heat the foam uniformly and to the same temperature as the milk, and consequently, micro-organisms present in the foam may survive pasteurization. If the inlet valve is at the bottom of the vat, foam formation can easily be prevented. A lid or cover on top of the vat promotes a uniform temperature of the contents and prevents skin-forming on the milk.

Cooling the milk after pasteurization by circulating a refrigerant – in most cases cold water – through the jacket of the vat may take much time. Therefore, a separate small-capacity surface, tubular or plate cooler may be used to rapidly cool the milk to the required temperature. This system also has the advantage that the vat will be available sooner for the pasteurization of another batch of milk.

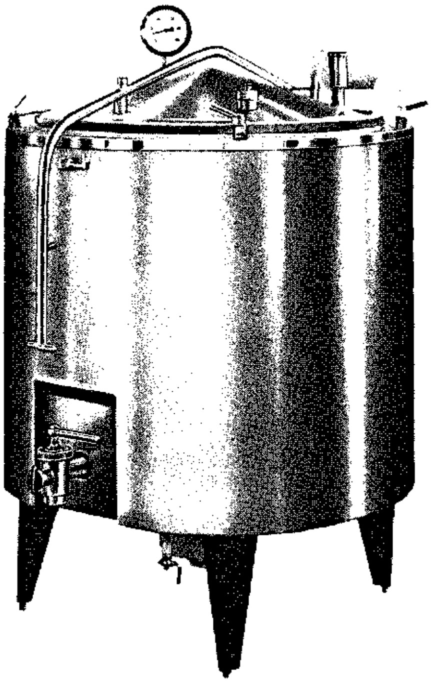

Fig. 31. Vat pasteurizer. Vat pasteurizers have various uses, including the pasteurization of milk and milk products, the production of fermented products and the cooking of custards. Courtesy: Machinefabriek Terlet N.V.

To preserve the natural properties of the milk, a moderate heat treatment, e.g. pasteurization at 63 to 65 °C for a period of 30 minutes can be applied. Milk for cheese making should receive a similar heat treatment, but milk for the production of fermented milks usually undergoes much more intensive treatments.

It is often possible to manufacture fermented liquid milk products and cheese in the same vat in which the milk is pasteurized and cooled to the required processing temperature.

6.2.1.2 In-package heat treatment

If milk for liquid consumption (liquid milk) is packed into retail packages after pasteurization, recontamination of the milk should be avoided as much as possible, to ensure the milk will have a proper keeping quality. As sterilized milk should be absolutely sterile, recontamination is totally unacceptable. It is difficult to avoid recontamination from airborne infection and from contact with the equipment and packaging material. For this reason, in-package pasteurization and sterilization of milk has definite advantages, especially under primitive conditions, where the hygienic quality of the milk is difficult to control. Moreover, in-package heat treatment is possible under conditions of small-scale operation.

In the event of in-bottle pasteurization, the bottles can be closed by simple aluminium capsules or similar closures, provided care is taken that the vacuum formed in the bottle during heat-treatment cannot suck water into the bottle during cooling.

In the event of in-bottle sterilization, the bottles should be sealed with air- and water-tight closures. Generally, crown corks are used (Section 6.4).

Pasteurization in a water bath

In-package pasteurization of milk in plastic sachets or in bottles in a water bath is the simplest method for small-scale operation.

Plastic sachets. Plastic sachets (see Section 6.4) of milk are put in a wooden or metal tank filled with water. If steam is available, the water can be heated by direct steam injection through a pipe or a hose inserted in the water, or by heat transmission, for which purpose the tank may be equipped with steam pipes or coils, or a double jacket. In its most simple design and for a small milk plant, a hand-operated filling device for plastic sachets and a big metal pan over an open fire are sufficient for in-sachet pasteurization. After the sachets have been filled and closed by heat sealing, they are inserted in the pan of water. The water is then brought to pasteurization temperature (e.g. 80 °C) and kept at this temperature for some time (e.g. 5 min). Then the hot water is replaced by cold water to cool the milk in the sachets, or the sachets are transferred to another tank with cold water.

The water with the sachets should be stirred during the heat treatment. The sachets must be full, to prevent them from floating.

If not enough cold water is available, the sachets should be cooled to the lowest possible temperature and transferred to a refrigerator or cold store immediately thereafter.

Bottles. A procedure similar to that used for the pasteurization of milk in sachets can be followed. The filled and sealed bottles are put in the crates in which the milk will be distributed. The crates of bottles are put in a rectangular tank, with steam and water pipes underneath a false bottom.

Although the system is simple in its design, certain precautions have to be taken. The level of the water in the tank should come above the level of the the milk in the bottles, otherwise the top layer of the milk may not be sufficiently heated. After pasteurization, the bottles of milk should be cooled as quickly as possible by supplying cold water to the tank continuously. The tank must be equipped with an adjustable siphon for the discharge of the water. If the bottles are not hermetically sealed, for instance with crown corks, they should never be covered with water during heating and cooling.

It is important to ensure that the milk in all bottles is heated uniformly: this requires the heat to be evenly distributed throughout the tank. The temperature can be checked with glass- or dial-type thermometers, preferably with the sensor in a bottle of milk or in a bottle of water.

In the event of in-sachet pasteurization it will be impossible to measure the temperature of the milk in the sachets, and reliance must be placed on the temperature of the water. In this case it will make a difference whether the sachets are put in cold or lukewarm water (where they will closely follow the temperature of the water while the temperature of the water increases up to the pasteurization temperature) or whether they are put in warm water (where it will take less time for the milk to reach the pasteurization temperature). In the latter case it may be found necessary to keep the sachets a few minutes longer in the water at the required pasteurization temperature.

Sterilization in a water bath

Autoclaves of various design are used for the sterilization of milk in a water bath. They are robust, cylindrical or rectangular containers, with doors or lids for loading and unloading. Valves are fitted to admit or discharge water, steam and air. The stationary autoclave in which the bottles are not agitated is the simplest design of a sterilizer.

After the sterilizer has been filled with bottles – usually loaded in crates – it is closed, and water is admitted. The air available in the autoclave is forced out through air vents. After the air has been expelled and all vents and openings have been closed, steam is admitted until the desired temperature in the autoclave has been reached (110-120 °C). This temperature is maintained for a period of 20 to 30 minutes to achieve proper sterilization. The sterilization temperature is preferably measured by putting the sensor of the thermometer in a bottle of milk or water in the sterilizer. After sterilization, the steam inlet is closed and the excess pressure in the autoclave is released, for instance by opening the air vents. Thereafter, the water is drained and the autoclave can be opened for unloading.

To prevent bottles from breaking, it is advisable to cool the bottles by gradually replacing the hot water by cold water in such a way that the difference in temperature between the milk and the water never exceeds 25-30 °C (the acceptable temperature shock also depends on the quality of the bottle). When the water has reached a temperature of about 50-60 °C, depending on the ambient temperature, it can be drained off and the bottles can be removed without too much risk of breakage. To preserve the quality of the milk, it is advisable to continue the cooling, either by sprinkling water or by blowing air, after the bottles have been removed from the autoclave.

Prolonged cooling may result in the milk acquiring a cooked flavour and brown colour. This also happens if the period of warming up to the sterilization temperature is too long, e.g. if heat transfer is poor. Heat transfer can be improved – and consequently the time of warming up and cooling down can be decreased – by agitating the bottles during heat treatment. This is accomplished by using rotary or tumbling sterilizers. Either the shell of the sterilizer is fixed and a frame containing the bottles rotates, or the sterilizer as a whole rotates. These sterilizers are generally cylindrical in shape (Figure 32).

Pasteurization in steam chests

In-bottle pasteurization of milk in steam chests is achieved by direct contact between

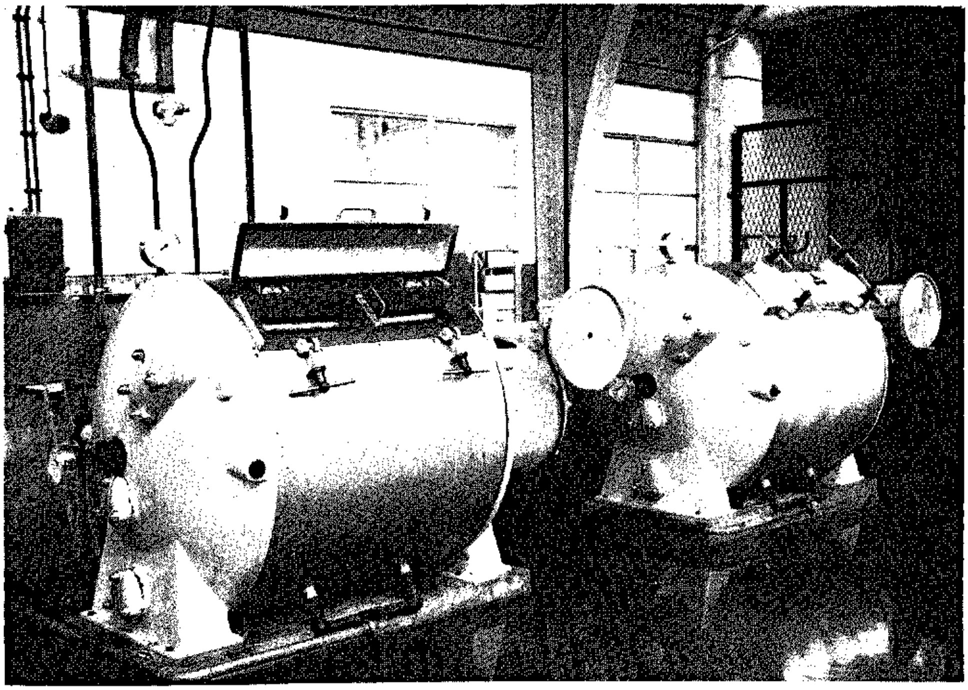

Fig. 32. Rotary sterilizers. Courtesy: Stork Amsterdam B.V.

the bottle of milk and the steam. The steam is usually introduced into the chest by means of a system of perforated pipes under a perforated false floor. The condensate is discharged by a discharge pipe connected with the space under the false floor.

There are two principal designs of steam chests: the cabinet-type and the hood-type. The cabinet pasteurizer consists of a fixed cabinet with a door (Figure 33). The hood pasteurizer consists of a fixed perforated floor and a cover that can be lifted with a pulley.

Steam chests are normally equipped with a manometer and a thermometer indicating pressure and temperature in the chest. It is advisable to monitor the temperature in the chest, using a long-distance thermometer that has its sensor in a bottle of water but which can be read off outside the chest.

To avoid the presence of air pockets and consequently of cool zones during heating, air should be forced out through air vents by the steam. Thereafter, during pasteurization, the valves are closed. When the correct pasteurization temperature has been reached, the steam supply is decreased to maintain this temperature during the entire period of pasteurization. The steam supply is then closed, and the air vents are opened.

The milk and bottles are very hot at the end of the pasteurization process and therefore there is a considerable risk of breakage if the steam chest is unloaded immediately. Therefore, bottles may be kept in the cabinet pasteurizer for a while after the door

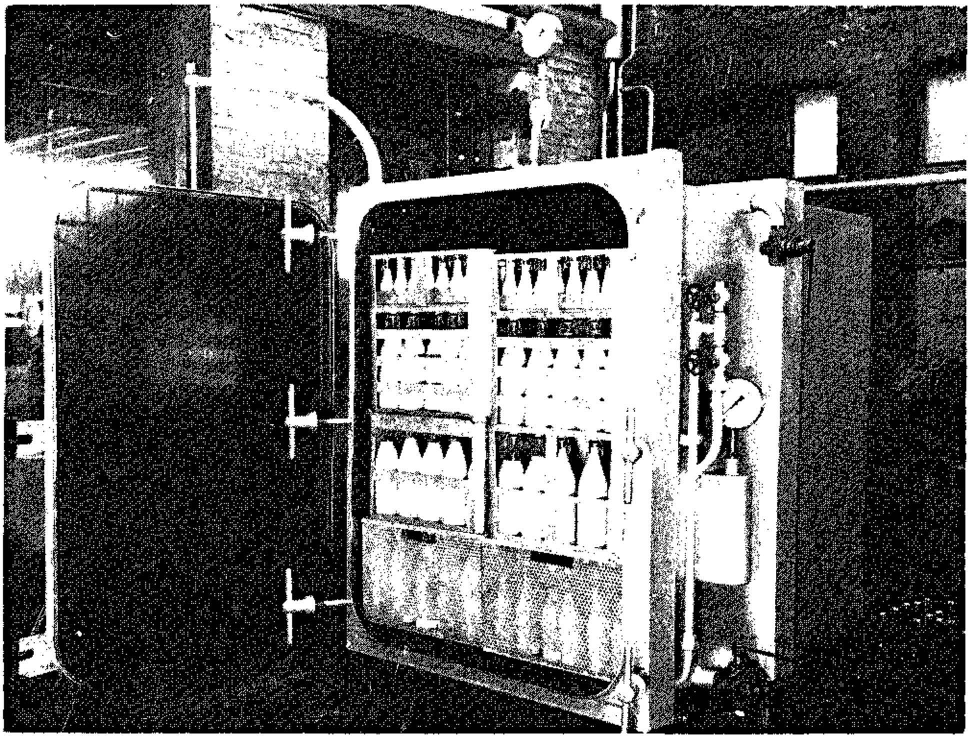

Fig. 33. Cabinet sterilizer. Crates of swing-top bottles are stacked in the cabinet. Similar cabinets of lighter construction can be used for in-bottle pasteurization. Courtesy: Stork Amsterdam B.V.

has been opened, to allow them to cool before they are removed.

Bottles sealed with aluminium caps will show a vacuum after pasteurization. It is not advisable to cool such bottles immediately by spraying them with water, because the vacuum may suck water into the bottles. Once the temperature of the milk has dropped to about 45 °C, water may be sprayed over the stacks of crates to cool them.

Sterilization in steam chests

The procedure for the in-bottle sterilization of milk in a steam chest is similar to that for pasteurization. Since there will be a pressure of at least 2 atm in the chest during sterilization, the construction must be robust enough to withstand this pressure. Steam chests constructed for in-bottle pasteurization must never be used for sterilization. The temperature in the steam chest is raised in a similar way as in the pasteurization process, but to a higher level and for a longer period, for instance to 110 to 120 °C for 20 to 30 minutes. After sterilization, the steam under pressure is slowly released, after which the door of the sterilizer can be opened.

As a result of the higher temperatures, even more care should be taken to avoid breakage of bottles than in the pasteurization process. Quick cooling, which is important for the quality of the product, can be achieved without too much risk of breakage of bottles, by sprinkling the bottles with water that is no more than 25 °C below the temperature of the milk. This cooling-process should start with 'hot' water from a special water container that is fed with the condensate formed in the steam chest during sterilization. The temperature of this cooling water can be gradually decreased by adding cold water to the contents of the container.

6.2.1.3 Advantages and disadvantages of the holder system

The methods of holder pasteurization and sterilization are especially suitable for small-scale operations, because the costs of investment and maintenance are comparatively low.

On the other hand, the disadvantages are considerable. They include a hot and humid atmosphere caused by the release of steam, and an inefficient use of steam and cold water. Moreover, labour costs are high.

A relatively long time is required to warm up and cool down the milk before and after heat treatment: this adversely affects the quality of the product.

When the heat treatment is applied to milk in bottles, it is difficult to achieve an even distribution of the heat, especially in the case of the direct steam method. Therefore, the time-temperature combination chosen must guarantee that the milk in all bottles will undergo the minimum required heat treatment. Inevitably, this means that some milk will receive a more intensive heat treatment than strictly necessary.

In order to reduce the warming-up period, the milk may be bottled hot. For this purpose the milk can be preheated in a continuous-flow pasteurizer or sterilizer – a system that is specially used to produce sterilized milk. After heating the milk to a temperature of 65 to 70 °C, or after regeneration to this temperature after prepasteurization or presterilization, the milk is bottled. To avoid breakage, the temperature of the bottles should not differ too much from the temperature of the milk. This is achieved by discharging the bottles from the bottle washer at the required temperature and leading them directly into the bottle-filling equipment.

The intensity of the heat treatment can be further reduced by ultra-high presterilization in continuous flow, that is 3 to 4 seconds at 135 to 140 °C, followed by cooling in a regeneration section to about 65 °C, after which the milk is led into the filling equipment. Presterilization at ultra-high temperatures will allow for a less intensive in-bottle sterilization afterwards, because the milk has been sterilized already and the in-bottle sterilization is only necessary to kill the few micro-organisms present in the bottle and in the milk as a result of recontamination. Presterilization followed by a less intensive in-bottle heat treatment causes a smaller loss of the organoleptic quality of the milk than does a more intensive treatment without presterilization.

Filling bottles at high temperatures has a sterilizing effect on the equipment (fillers and pipelines) and bottles. On the other hand, if temperatures are not high enough, there is a risk that thermophilic bacteria will develop.

6.2.1.4 Continuous process of in-bottle sterilization

The holder system for in-bottle sterilization is less suitable for large capacities. The continuous mechanical process overcomes this disadvantage. Moreover, as a result of a better controlled heating and cooling system, uniformity of taste and appearance can be expected, and the risk of breakage is smaller.

In this system, bottles of presterilized milk are carried through a number of vertical columns. The bottle carriers are 8-20 bottles wide and are attached to two chains, which move through the vertical columns; the so-called hydrostatic system (Figure 34). The pressure in the heating/sterilizing-chamber in the system is obtained by the water pressure of vertical columns of water at the inlet and the exit columns. The area between the two columns is the steam area. The pressure and the resulting temperature in the steam area depends on the heights (actually the differences in height) of the water columns in the hydrostatic seals (augmented by the atmospheric pressure). The temperature of the water in the columns and the steam area is controlled by the introduction of steam and water.

The bottles gradually heat up during their journey through the columns of the sterilizer before entering the steam area, and gradually cool down after they have passed this area. Since the bottles are filled with hot presterilized milk, they enter the sterilizer at a high temperature. After sterilization the milk is cooled to 40-45 °C.

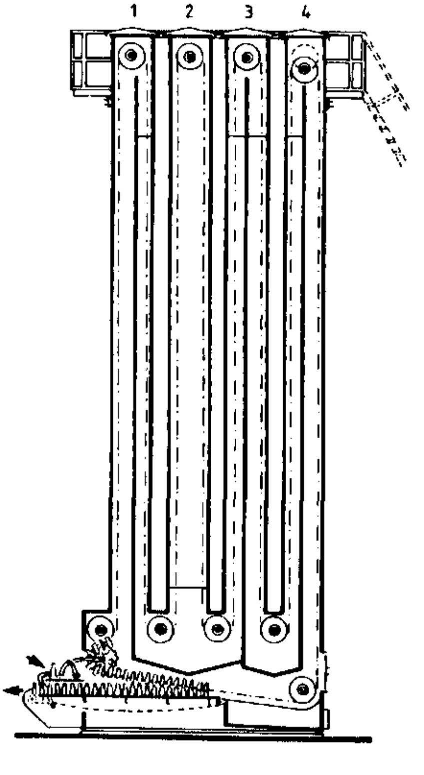

Fig. 34. Schematic representation of a continuous in-bottle sterilizer; with columns for preheating (1), sterilization (2) and cooling (3, 4). Courtesy: Stork Amsterdam B.V.

6.2.2 Continuous-flow systems

Although a number of batch heat exchangers can be combined in such a way that they give the process a more or less continuous throughput, the introduction of modern continuous-flow pasteurizers and sterilizers has led to far more efficient procedures, which allow for a much quicker heating and cooling of the milk. Moreover, these exchangers are of the closed type.

The continuous-flow systems have a number of advantages:

- The system is more compact and requires little space.
- The system is simpler to operate and easier to control. Temperatures can be controlled within very close limits.
- Higher temperatures can be used, without affecting the organoleptic quality of the milk too much; furthermore, more micro-organisms are killed and enzymes inactivated.
- A more economic use is made of cold and heat.
- Less humidity is developed in the processing localities.

During heat treatment, a deposit of milk solids may accumulate on the heat-exchange surfaces. This gradually lowers the rate of heat transfer and increases the resistance of the apparatus. Under some conditions, thermophilic bacteria may develop in the deposit at suitable temperatures. During long periods of processing, intermediate sanitization of the plant will be necessary to ensure an optimal heat transfer and to eliminate bacterial growth.

Continuous-flow systems are less suitable for small-scale operation (i.e. for capacities below 2000 l/h). They are either plate heat exchangers or tubular heat exchangers.

Plate heat exchangers. A plate heat exchanger consists of a number of thin – preferably stainless steel – plates (Figure 35) separated by rubber gaskets, forming sealed narrow chambers between each pair of plates. A certain number of plates forms a section (Figure 36). A number of sections are clamped together in a frame. Milk and a heating or cooling medium flow through the alternate chambers in such a way that milk flows along one side of each plate and the heating or cooling medium along the reverse side. The plates in a section are mostly arranged in such a way that the liquids flow counter-current (in opposite directions), but arrangements that allow for concurrent (parallel) flows are also possible. Openings in the corners of the plates allow for connections between chambers that contain the same liquid.

Tubular heat exchangers. A tubular heat exchanger consists of a number – usually two, but occasionally three – of concentric tubes, generally assembled to form a section, similar to the chambers in a plate heat exchanger. Milk and a heating or cooling medium flow through the inner tube and the space between the concentric tubes in counter-current.

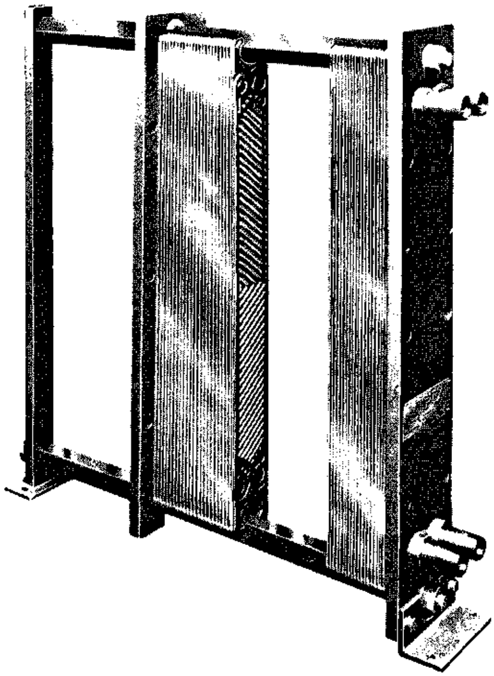

Fig. 35. Plate heat exchanger (APV 'Junior') for small-scale or laboratory work in opened position; plate visible. Courtesy: APV Crepaco Europe S.A.

6.2.2.1 Continuous-flow pasteurizers

Continuous-flow pasteurizers are either plate heat exchangers or tubular heat exchangers. In the sections of the continuous heat exchangers the various procedures of the pasteurization process take place, namely: regeneration, heating, holding and cooling of the product (Figure 37).

Regeneration section

In the regeneration section, the cold milk coming from a balance tank flows in countercurrent to the hot pasteurized milk. This arrangement results in the cold milk being warmed up and the hot milk being cooled down. The more heat is transferred in the regeneration section, the less extra heat has to be introduced to attain the pasteurization or sterilization temperature, and the less cooling water is needed.

The degree of regeneration, and as a result the efficiency of operation, can be improved by increasing the number of plates (or number or length of tubes) in this section. However, a larger number of plates requires a larger investment. Moreover, this results in a higher counter-pressure of the installation, making it necessary to install a milk pump that can develop a higher pressure. It will also take more time and energy to warm up the installation before processing can start and during sanitization.

The most efficient rate of regeneration depends on local conditions, especially the time of operation, and the availability and the price of energy and cooling water. Heat

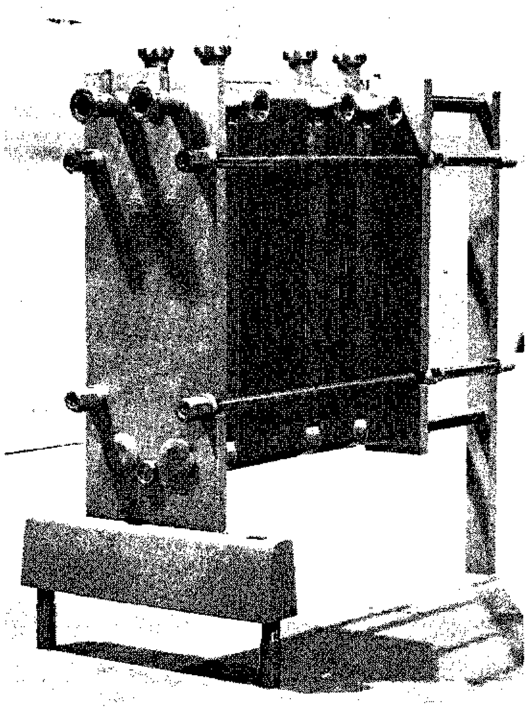

Fig. 36. Plate heat exchanger with sections for heating, cooling and regeneration. Courtesy: Alfa Laval Food Engineering AB.

exchangers for the pasteurization of milk usually have a high rate of regeneration, for instance 90%. If the temperature of the raw milk is 5 °C and the milk has to be pasteurized at 72 °C, 90% of regeneration would mean that the temperature of the raw milk can be increased by $90/100 \times (72-5) = 60.3$ °C to reach a temperature of 65.3 °C. The pasteurized milk will be cooled to $72 - 60.3 = 11.7$ °C. In this calculation no losses of heat and cold are taken into consideration.

Many pasteurizers have a two-stage regeneration section. After the first stage the milk can be passed to the separator or clarifier (when its temperature is approximately 45 °C), or to the homogenizer (when its temperature is approximately 65 °C).

Milk pasteurized for the production of cheese or fermented milk products will be cooled to the renneting or fermentation temperature if the milk is directly transferred to the processing vat. In such an arrangement the regeneration section is comparatively small.

Heating section

The milk coming from the regeneration section will be heated to the pasteurization temperature in the heating section. In most cases the heating medium will be hot water or low-pressure steam. Milk and water will flow through the section in opposite directions. It is a good idea to install automatic devices for temperature control and registration in pasteurizers.

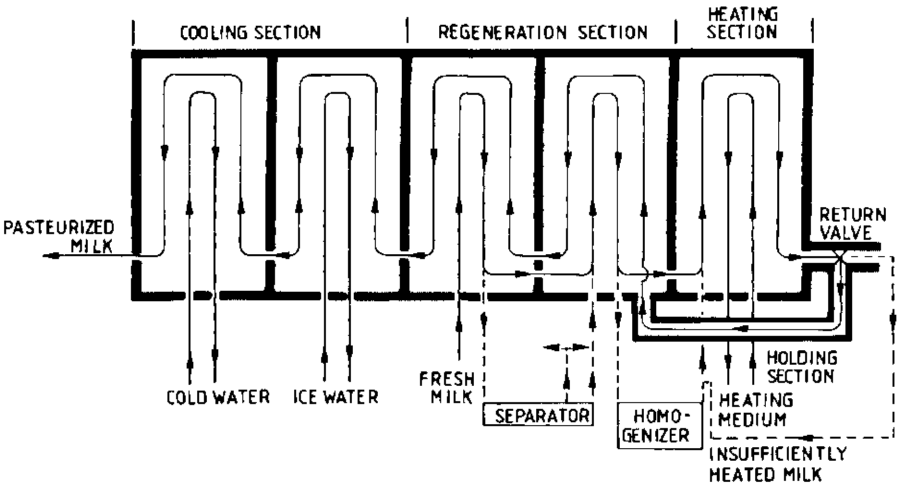

Fig. 37. Flow diagram of pasteurizing plant. Source: Walstra, P. & A. Jellema. Dairy Technology. Syllabus, Wageningen Agricultural University (in Dutch).

Holding section

After the milk has reached the pasteurization temperature it enters the holding section, where it is held at this temperature for the required pasteurization period. The holding section may either consist of one or more wide chambers inside the frame of the pasteurizer, or one or more tubes on the outside of the pasteurizer.

Many pasteurizers, especially those used for the production of liquid milk, are equipped with a flow-diversion valve situated at the outlet of the holding section. This valve functions as a safety valve; it will lead the milk back to the balance tank for raw milk as soon as the pasteurization temperature drops below a certain critical level.

Cooling section

After the milk has passed the holding and regeneration section it is cooled with cold water from a well or the mains, and thereupon deep-cooled with brine or ice-water, or by means of direct evaporation of a refrigerant. Under tropical conditions cold water may not be available. In these cases, the cold-water section can be left out.

Milk entering a pasteurizer at a temperature of 5 °C will leave the regeneration section at a temperature of approximately 19 °C, provided the regeneration rate amounts to 80%. It is very unlikely that sufficiently cold water for precooling this milk will be found under tropical conditions. However, if the milk enters the pasteurizer uncooled, for instance at 30 °C, it will leave the pasteurizer at 38 °C and the possibilities of precooling should be considered.

Since the temperature of the outgoing milk depends on that of the incoming milk, special care should be taken if the temperature of the incoming milk fluctuates. The milk in the deep-cooling section of a pasteurizer may freeze if deep-cooled milk is fed to the pasteurizer instead of 'warm' milk.

6.2.2.2 Continuous-flow sterilizers

Continuous-flow sterilization (CFS) of milk in plate or tubular heat exchangers (see continuous-flow pasteurizers) is well possible. The higher the temperature of heat treatment, the greater the sterilizing effect and the more marked the change in colour and taste of the milk will be. However, the spore-reduction rate increases much faster with increasing temperature than does the change in colour and taste. This means that with increasing temperatures the time of sterilization can be shortened to obtain the same bacteriological results and an organoleptically more acceptable product. This phenomenon has led to the introduction of sterilization techniques that combine very high temperatures with very short times. Very short heat treatments have been made possible by the introduction of systems that allow for a quick transfer of heat and cold. Two systems of CFS can be distinguished:

- CFS followed by in-bottle sterilization,
- CFS followed by aseptic filling.

CFS with in-bottle sterilization

As explained before, milk is bottled after CFS, but has to be sterilized again to kill recontaminating germs and their spores. Although this two-stage process allows for a product with a less 'sterilized flavour and colour' than the one-stage in-bottle process, an even better product can be obtained by avoiding the second step of sterilization.

CFS with aseptic filling

Special equipment has been developed for the CFS sterilization of milk followed by aseptic filling (i.e. filling without contamination), which makes in-bottle sterilization unnecessary. This system is mostly referred to as ultra-high temperature sterilization or UHT sterilization. Although procedures have been developed for aseptically filling bottles of milk, the aseptic filling of disposable cartons or plastic sachets is more usual.

UHT preservation is also used when sterilizing other milk products, such as cream, evaporated milk, custards, etc.

UHT sterilizers are normally equipped with a regeneration section, where the cold incoming milk is preheated with the hot sterilized milk. Sometimes, water is used as an intermediate liquid which cools the hot sterilized milk and heats the cold milk. The milk may also be preheated by vapours from the sterilization section.

After the milk has passed through the regeneration section there are two possible ways of bringing it to the sterilization temperature:

- the indirect heating system,
- the direct heating system.

Indirect heating. Indirect heating is performed in heat exchangers. The principle of this system is very similar to the conventional continuous-flow pasteurization, since

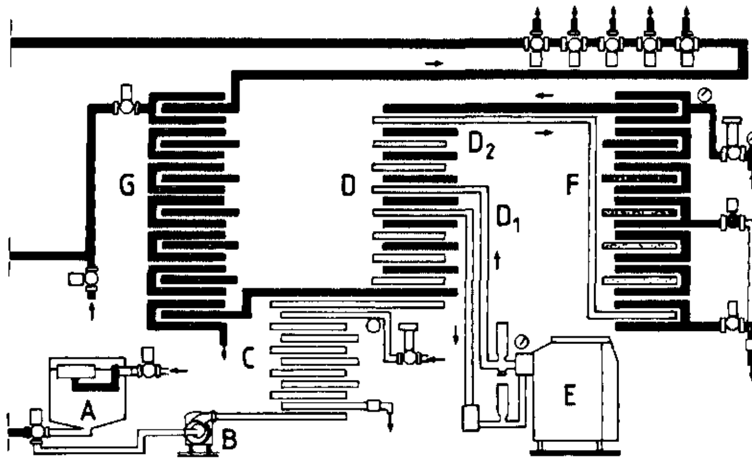

Fig. 38. Indirect UHT sterilization. The 'sterideal' process for sterilization. The pump B is fed from tank A and forces the product through the circuit sterilizer (C) to the regeneration section D, where preheating takes place. In part D_1 a temperature of about 65 °C is reached and a by-pass leads the product to the homogenizer E. After homogenization the product is forced through the second part of the regeneration section (D_2) and from there to the UHT sterilization section (F) where it is heated with steam to the final sterilization temperature. Thereafter, the milk flows through the regeneration section to the cooler G, where it flows in counter-current with cooling water. The circuit sterilizer is used to heat water to sterilize the equipment before processing starts; it has no further function in the plant. Courtesy: Stork Amsterdam B.V.

the heat is transferred through stainless steel walls (Figure 38). Depending on the method, in most systems the milk is heated to a temperature of 135-150 °C, and kept at the sterilization temperature for a very short period, in most cases between 3 and 10 seconds, although shorter as well as longer periods are applied.

Direct heating. Direct heating is performed either by injecting steam into milk or vice versa (Figure 39). As a result of the direct contact of steam and milk, the steam gives up its latent heat and very quickly brings the milk to the sterilization temperature, which, depending on the method, varies between 140 and 150 °C. After holding for only 3 to 10 seconds the milk passes to a vacuum chamber where the excess water resulting from the condensed steam is removed by evaporation. The heat required for this evaporation is extracted from the milk, allowing it to cool down instantaneously to its approximate temperature immediately before sterilization.

It may be expected that the vacuum treatment will remove some if not all of the off-flavours present in the raw milk. Since no vacuum chamber is essential in the indirect system of UHT sterilization, some of these sterilizers have a special de-aerator in the regeneration section.

Steam that comes into direct contact with milk should be of extremely high quality. It must be absolutely pure and may not have any off-flavour. Care must be taken that water that enters the boiler for steam production is of good quality.

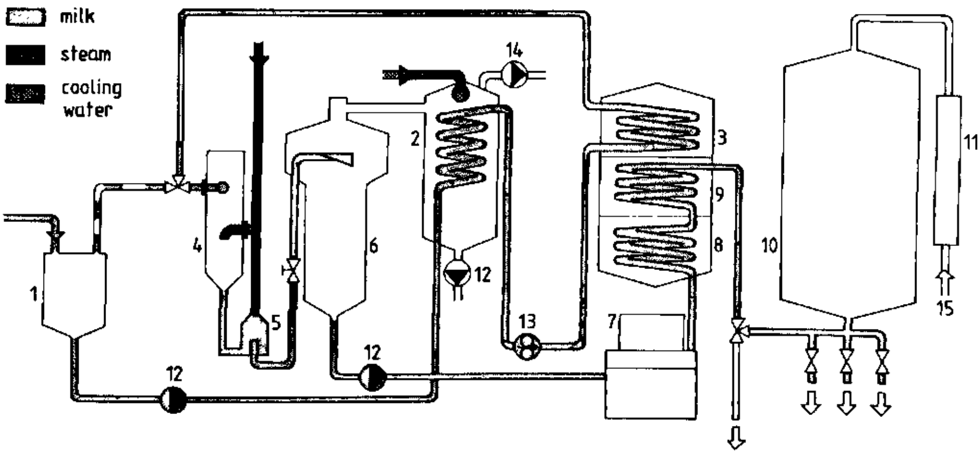

Fig. 39. Direct UHT sterilization. From the balance tank (1) the milk is pumped through the 2-stage preheater (2 and 3) where it is heated to 75 °C, in the first stage by vapour from the vacuum chamber and in the second stage by live steam. The milk is then sprayed into the steam-filled sterilizing chamber (4) and heated instantaneously from 75 °C to 145 °C and held for a few seconds at that temperature in the holding chamber (5). The product flows to the vacuum chamber (6) where it is 'flashed' down to 77 °C. An aseptic centrifugal pump (12) conveys the sterilized milk, which has the same composition again as the raw milk, to an aseptic homogenizer (7). The homogenizer delivers the milk to a 2-stage cooler (8 and 9), where the milk is cooled to about 25 °C with cold water and/or chilled water. The cooled milk flows into a sterile tank (10) or directly to an aseptic filling machine. 11: air filer; 12, 13, 14: various types of pumps; 15: air inlet. Courtesy: Pasilac AS.

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6.3 Heat treatment by irradiation

UV radiation

The equipment used to pasteurize or sterilize milk by ultraviolet irradiation consists of quartz tubes irradiated by light emitted from a series of UV light tubes. The milk is pumped through the tubes at a high velocity. However, effective UV radiation of milk affects its flavour. To enrich milk with vitamin D_3, a lower dosage than is required for effective pasteurization may be applied. In many countries, UV radiation is prohibited.

Infra-red radiation

Heat treatment by infra-red irradiation is made possible by pumping milk through quartz tubes around which electric elements are coiled. The tubes are connected by stainless steel end-caps. Electricity passing through the coils of these elements heats them to 800 °C. This results in an emission of infra-red radiation which passes through the quartz tubes without heating the tubes themselves. In this way the milk is heated without coming into direct contact with a heating surface (Figure 40).

Milk and other products to be heated pass through the tubes in a turbulent flow. They can be pasteurized, as well as sterilized at different temperatures, by controlling the intensity of radiation by means of resistors in the electrical circuit and by varying the rate of throughput of the product. The tubular system in combination with the direct heat transfer ensures long processing runs, because the deposition of milk constituents in the heating section is negligible.

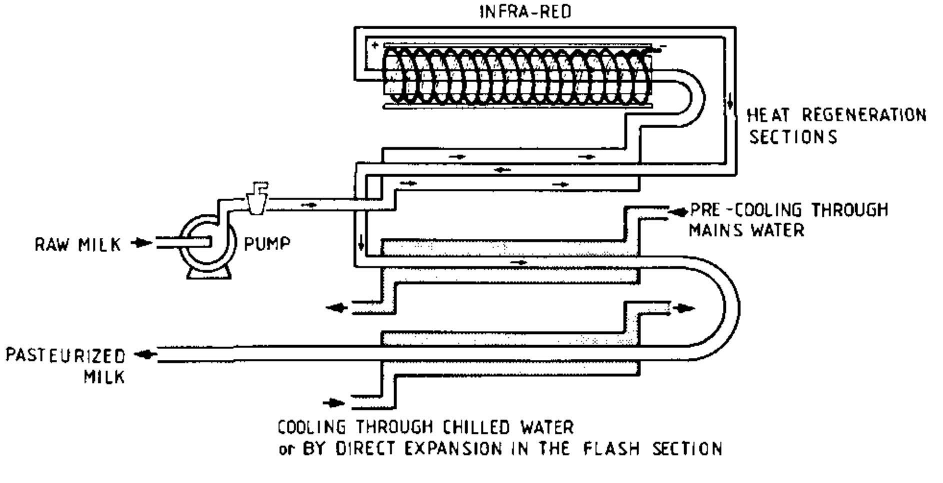

Fig. 40. Pasteurization of milk by infra-red irradiation. Courtesy: Actini France S.A.R.L.

Although the tubes are sufficiently resistant to breakage under normal conditions, sudden and large changes in the pressure of the liquid should be avoided. The pressure in the tubes depends amongst other things on the capacity of the equipment, the temperature to be reached, the type of the product and the deposition in the tubes.

For special purposes (e.g. UHT sterilization) the quartz tubes can be equipped with a stainless steel inner tube. Similar to other systems of heat treatment, the infra-red pasteurizer can be equipped with regeneration and cooling sections (the latter for direct as well as indirect cooling). Small-capacity, portable equipment using this system is available.

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6.4 Retail packaging of milk and liquid milk products

6.4.1 Distribution of loose milk or packaged milk

The costs of packaging pasteurized and sterilized milk are high and as such they increase the price of the product considerably. Therefore, serious consideration must be given to whether the advantages of packaged milk justify the higher price, especially because the lower income groups may be unable to pay such a price or to buy sufficient quantities of milk for such a price.

The main advantages of packaging of milk are protection against recontamination and adulteration. Recontamination of unpackaged milk cannot be avoided. This will affect the keeping quality, but it may also be the cause of propagation of disease, if the milk is contaminated with pathogens. This risk, although considerable, should not be overrated in areas where the population is used to boiling the milk immediately after purchase. Loose milk is easy to adulterate, especially by adding water.

A system of retailing pasteurized milk through automatic vending machines will largely solve the problems mentioned above. This system uses a milk storage tank of sufficient capacity, from which the milk is discharged as required through a coin-operated dispenser. The tank must be insulated or placed in an insulated and refrigerated room. Facilities for CIP sanitation should be available. The milk is delivered to the storage tank by road tanker (Figure 41).

To protect raw milk against adulteration and to avoid contamination during retail distribution, this milk may be sold in sealed containers. Farms may specialize in the production of raw milk of high hygienic quality for this purpose.

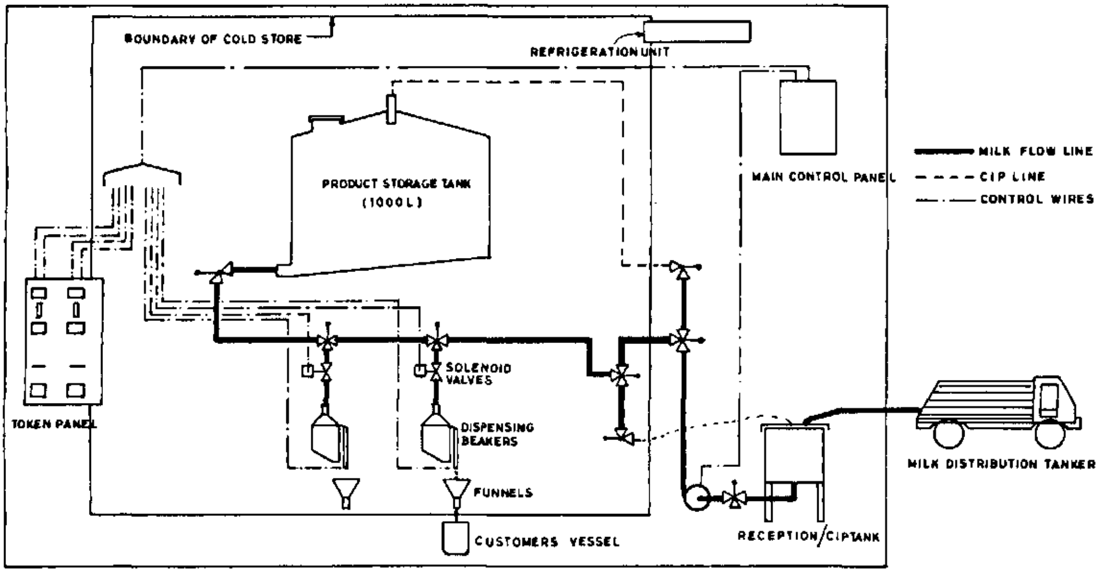

Fig. 41. Diagram of automatic bulk vending booth. Courtesy: Indian National Dairy Development Board.

6.4.2 Packaging of milk

The main materials used for the manufacture of milk containers for retail delivery are glass, paper or cardboard, and plastic. Paper and cardboard are always coated or laminated with other materials, such as plastic and aluminium. Plastics are usually coloured, or covered with a coloured coating to protect the contents against the influence of light. Sometimes, they are laminated with aluminium. Aluminium makes the containers impermeable to light and gases.

Milk containers are either of the returnable or the non-returnable type. The latter is also called single-service or one-way type.

Glass

Glass bottles are the traditional containers for the retail packaging of milk and liquid milk products (Figure 42). Bottles are used in various sizes up to 2 litres; they are generally round, but there is also a space-saving square bottle. Some milk plants distribute milk in one-gallon jugs. Bottles for pasteurized products usually have a mouth with a rather wide diameter (36-40 mm). The mouths of bottles for in-bottle sterilization are much narrower (26 mm), to allow for a more effective closure.

Aluminium foil caps made in a capping machine from a reeled strip are the most common closure for the wide-mouth bottles and have superseded the discs that used to be inserted in the neck of the bottle. Factory-made aluminium caps are used in hand-operated filling machines. The bottles are closed by pressing the overlapping part of

Fig. 42. Returnable glass bottles and non-returnable plastic cups. Courtesy: N.V. Vereenigde Glasfabrieken (United Glassworks).

the cap around the mouth of the bottle.

For in-bottle sterilization a much stronger closure, the so-called 'crown cork' is used. It is more a cap than a cork, and consists of lacquered tin plate, the inner surface of which is lined with a waterproof lining, e.g. cork. Upon closure, the wavy skirt of the crown cork is pressed into a ring that is around the mouth of the bottle, thus securing a seal. During sterilization, the crown cork allows the air that is pressed out of the bottle by the pressure of water evaporating in the bottle to escape. After sterilization, the water vapour in the bottle condenses, creating a vacuum, which sucks the lining of the crown cork tightly against the mouth of the bottle. The so-called 'swing stopper' is obsolete.

Glass bottles are usually reused 40 to 60 times under favourable conditions, but much lower figures are usually obtained under tropical conditions. Their durability makes them a cheap packaging system, but a number of disadvantages have to be taken into consideration. A major disadvantage is the necessity of collecting and rigorously cleaning (Section 13.3) empty bottles (the 'empties'), prior to re-filling or intermediate storage. It is not good practice to store dirty bottles, because milk residues will dry up and the bottles will be more difficult to clean afterwards. Storage of cleaned bottles has the disadvantage that bottles may become contaminated by dirt, bacteria and insects during storage. Therefore, bottles should be conveyed directly from the washer to the filler. If storage of bottles is unavoidable, it is advisable to wash them again before use. Collection, handling, cleaning and storage of empty bottles require much space and labour.

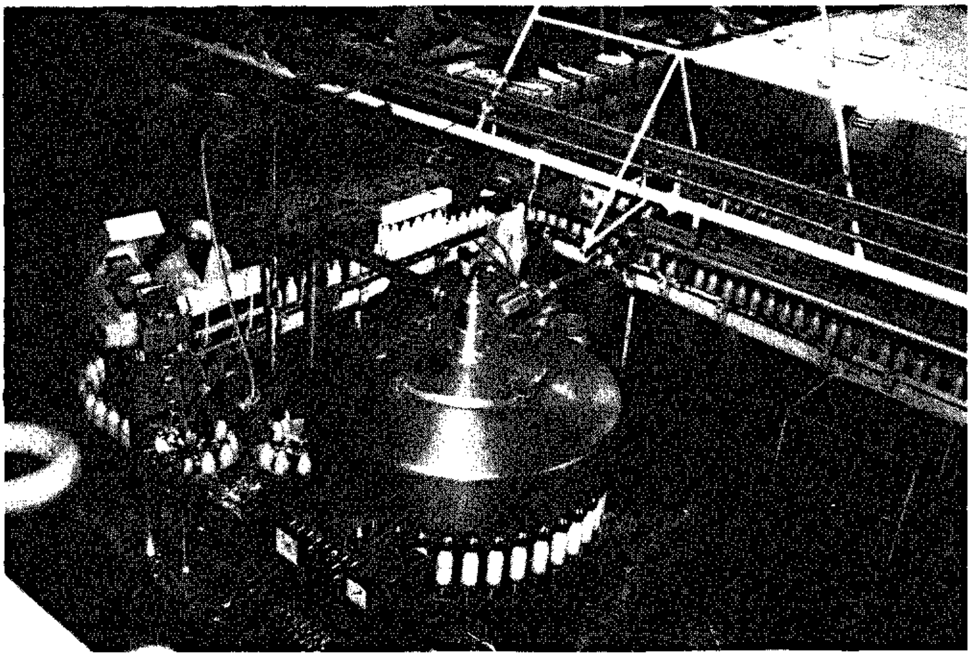

Fig. 43. Bottling plant. After filling in a rotary bottle-filling plant (centre, foreground), the bottles are closed with aluminium caps and carried off along a bottle conveyor. A bright light over the conveyor allows for inspection for irregularities. Photo: M.A. Luijkx.

To make sure that the consumer will return the empty bottle, a deposit has to be asked for. In many countries, consumers are unable or not prepared to pay a deposit.

Milk in glass is not protected against light and is subject to light-induced flavours.

Glass bottles are rather heavy. 'Light-weight bottles' have been introduced in a few cases, especially to serve as a non-returnable bottle.

Bottles are put in crates for protection and to facilitate handling. Crates were formerly manufactured of wood or galvanized iron wires or strips, but nowadays are made of plastic.

Filling and capping of bottles. Simple hand-operated or semi-automatic fillers and cappers can be used for small-scale operations, but most milk plants use fully automatic filling and capping equipment. Both fillers and cappers, have a circular array of pedestals on which the bottles are carried around (Figure 43). The bottles are filled during one round by means of filler valves constructed over the pedestals. The valves are fed from a bowl on top of the filler. As the bottles are being carried around, the pedestals lift the bottles against the valves, so they can be filled. At the end of one rotation the pedestals drop and the filled bottles can be moved towards the capping machine where the bottle is closed with an aluminium cap or a crown cork in one rotation.

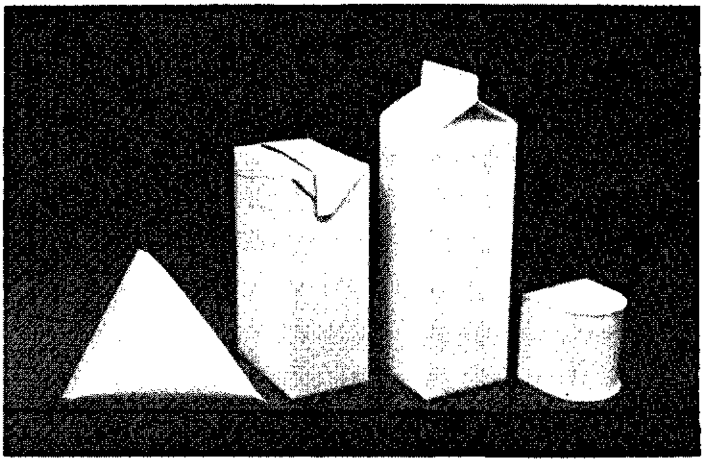

Fig. 44. Various types of milk carton. Courtesy: Tetra Pak International AB.

A few straight-line filler and capper models and in-crate fillers and cappers have been developed, but they have not been as widely used as the rotary types.

Transport of bottles. Special bottle conveyors transport the bottles from the place where the crates with empties are unloaded to the dirty-bottle washer, the filler and capper, and from there to the place where the bottles are put into the crates again. Uncrating and crating can be effected mechanically.

Paper and cardboard containers

Paper or cardboard containers (cartons) are all of the single-service type. The material used nowadays is a polyethylene (or other plastic) laminated or coated cardboard, but formerly, paraffin-coated materials were used. For some applications an aluminium lamina is incorporated.

This type of material has a number of advantages over glass bottles, such as lightness, no returns and no handling and washing of empties, less space required for equipment and storage, more protection of the milk against light, etc. The material costs of the single-service containers are higher than those of the multiple-service containers, if the number of rounds is taken into consideration. The total costs of operation and material are in most cases higher than those of glass bottles, mainly because the material costs are higher.

Paper containers are usually either cup-shaped or rectangular or tetrahedal-shaped (Figure 44). Some types of containers are factory-prefabricated, and only require filling and closing at the milk plant. In most cases the containers are formed in the milk plant. Some are pre-cut at the factory and supplied to the milk plant flat and 'knocked down', only needing to be formed into a container prior to filling. In other cases the containers are manufactured at the milk plant from a reel of material. Paper containers are generally closed by a heat seal. Small-capacity hand-operated filling and closing equipment (Figure 45) requires pre-fabricated containers, but transportation costs of these are much higher than of knocked-down containers and containers from the reel.

Filled cartons are distributed in crates adjusted to their shape, but flat-topped rectangular containers can be wrapped in non-returnable materials, e.g. shrink film.

Special equipment is used to aseptically fill paper containers with UHT-sterilized milk (Figure 46). The material used for the containers may have a special aluminium lining to protect the milk against the oxygen from the air. The equipment for aseptic filling must be handled with great skill and the costs of this system of sterilization and packaging are high. On the other hand, aseptically packed UHT milk has a prolonged storage life without refrigeration and consequently it is very useful for distribution in warm climates if no cold chain is available. In such cases it will be useful to compare the higher costs of aseptically packed UHT milk with the higher costs of the establishment of a satisfactory cold chain and the advantages of a larger number of sales points.

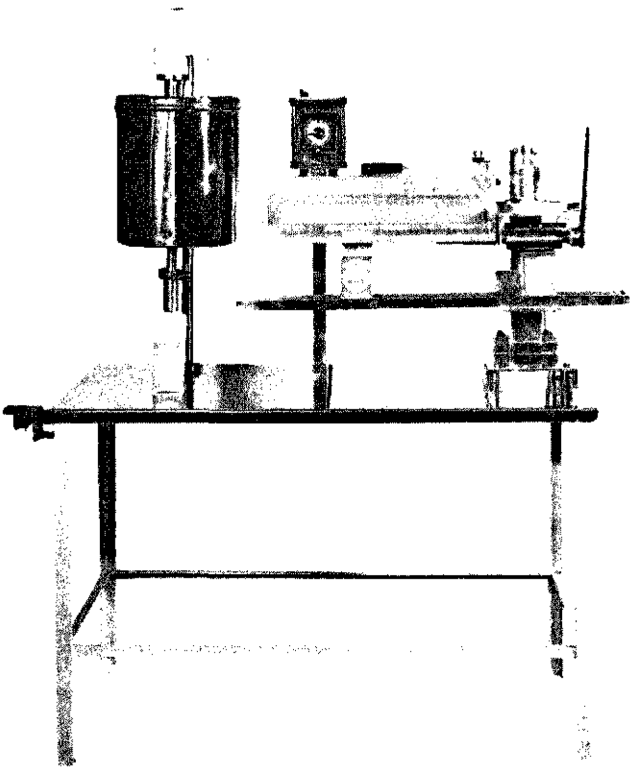

Fig. 45. Hand-operated carton filler. A carton is placed under the filler. When filled, it is put on the tray under the pre-heater. The next filled carton pushes it along to the right. It is placed under the sealer, the lever (at the far right) is pulled and the carton is sealed. Courtesy: Cockx & Sons Ltd.

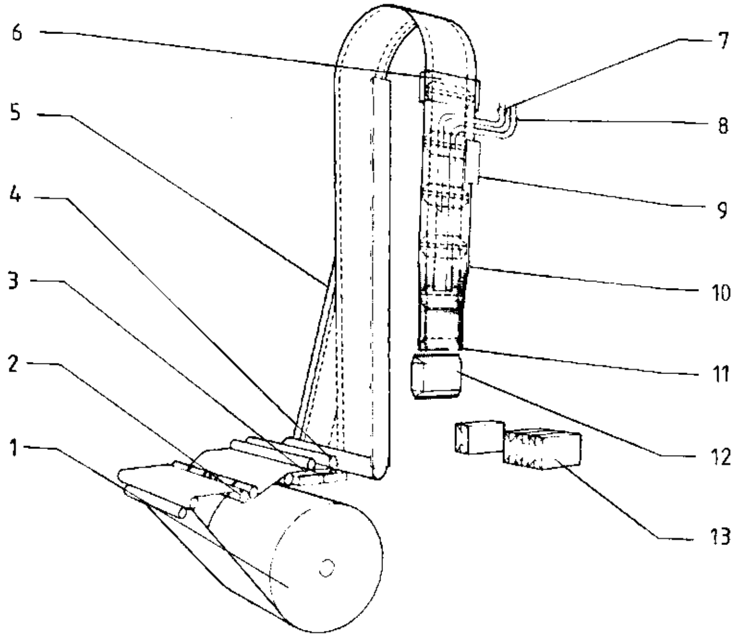

Fig. 46. Tetra Brik aseptic filling machine. From a roll (1), the packaging material passes between two rollers (2) which make the creases along which the top and the bottom of the carton are formed. Then, the packaging material passes between two rollers (3), the lower of which is located in a sterilizing bath. This contains hydrogen peroxide, which is applied to the inside of the packaging material. Two squeezer rollers remove most of the sterilizing hydrogen peroxide liquid (4). Proceeding upwards (5), the packaging material is folded double along the middle, and the inside of the material is covered by a stainless stell lamina. The chamber thus formed is under a constant pressure of sterilized hot air (approx. 125 °C), which evaporates the hydrogen peroxide remaining on the inside of the packaging material, preventing the entry of unsterile air from the premises. After the packaging material passes the highest point of the machine, creases are produced (6) along which the top and the bottom flaps of the carton, as well as its vertical edges, are formed. Sterilized air is blown into the folded paper tube through a pipe (7), so entry of unsterile air is prevented. Milk is introduced into the paper tube through a filling pipe (8), which emerges below the liquid level in the paper tube to prevent foaming; the level is regulated by a probe (10). The double-folded paper web is sealed by induction heat between two sealing jaws. The side seams of the cartons are sealed by induction heat from hydraulically-controlled jaws (11). Immediately prior to sealing, the carton is embraced by two plates which determine the amount of liquid in the carton and contribute to shaping it (12). The filled and sealed cartons are moved towards the discharge end of the machine, their top and bottom flaps being folded and sealed in the meantime (13). Courtesy: Tetra Pak International AB.

Plastics

Plastic bottles have been introduced as returnable and non-returnable containers for milk. They are mainly used in large-capacity milk plants. Plastic bottles may be factory-manufactured or blow-moulded in the milk plant from mixtures of high- and low-density polyethylene granules. Sometimes, other plastics are used. Plastic bottles can be filled with heat-treated milk, but they are also used for in-bottle sterilization.

The single-service plastic bottle is an expensive container and its economic use may be difficult to achieve in the smaller-capacity milk plants.

A very simple system of milk packaging makes use of low-density polyethylene sachets, which are either supplied in the form of stacks of pre-fabricated bags (Figure 47) that are filled and sealed in a revolving filling/sealing machine, or in the form of a reeled plastic tube that is filled with pasteurized milk from a balance tank. Transverse seals are made and the individual pillow-shaped packages are separated by guillotine. The sachets are packed in rectangular crates. The contents of the sachets are varied by varying the distance between two transverse seals.

The costs of packaging milk in plastic sachets are comparable with those for glass bottles. Small manually operated fillers and sealers make the system attractive for small-scale operation (Figure 48).

To protect the milk from light, the plastic of the sachet must be coloured.

Systems for aseptically filling plastic packaging materials (e.g. cups and sachets) with UHT milk (and other products) have been developed recently. Plastic sachets for UHT milk must be laminated in such a way that the product is protected against light and air (oxygen). If not, chemical deterioration will be noticeable between 2 and 10 days after production, depending on storage conditions.

Large plastic bags with a draw-off valve in cardboard boxes are principally intended for use in canteens and similar establishments.

Fig. 47. Plastic sachet of milk. Courtesy: Thimonnier S.A.

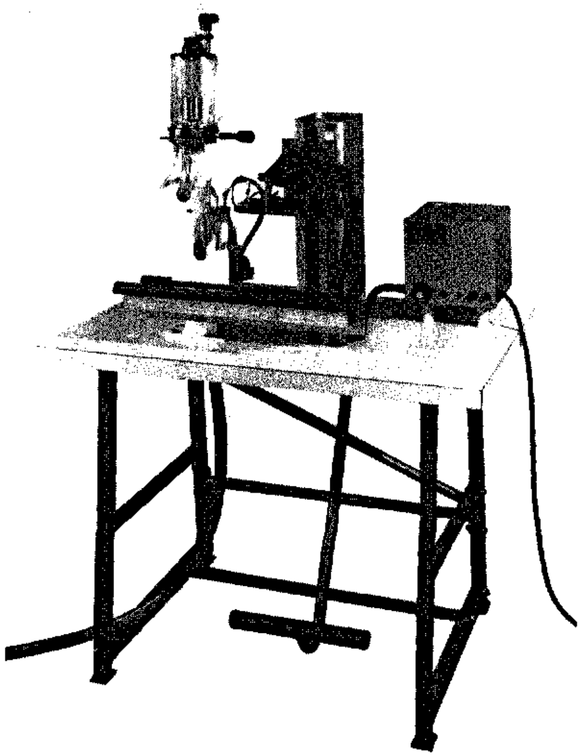

Fig. 48. Packaging of liquids in plastic sachets. The liquid is transferred to the transparent cylinder (left). When the required quantity has been attained, the tap is turned to fill the sachet under the cylinder. The sachet is then moved over an open steel supporting frame to the heat welder. The sachet is positioned between the welding clamps and heat-sealed by pressing the foot pedal. Courtesy: Thimonnier S.A.

As a result of the packaging procedure, the temperature of the milk may have risen a few degrees Celsius. To prevent further increases in temperature or to bring the temperature of the milk down again if it has risen too much during packaging, the packaged milk should be put in cold store as quickly as possible. Since there is no air circulation in crates filled with milk in rectangular or tetrahedral-shaped containers or plastic sachets, milk in these packages will show a slower rate of cooling than milk in bottles. On the other hand, the rise in temperature during uncooled distribution will be slower. The packaging materials described so far are used for all kinds of liquid milk products, although their suitability depends on the consistency of the product. Plastic cups with capacities ranging from 10 to 500 ml are quite popular (see Figure 42). In most cases the smaller cups are destined for single-service packaging of cream and concentrated milk. The cups are aseptically packed and closed by an easily-removable plastic lid. The larger cups are especially used for viscous products like fermented milk products, custards and the like. They are usually sealed with an aluminium cover.

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See also 'Further reading' Section 6.2

6.5 Quality and keeping quality of liquid milk

There are many reasons why heat-treated liquid milk may be of poor quality or why its quality rapidly deteriorates. Below, only the causes of the most important defects will be discussed.

6.5.1 Flavours

Absorbed flavours

Raw milk easily absorbs flavours during production, handling, and storage. Enzymatic activities in raw milk may also cause off-flavours. These flavours will generally not disappear during heat treatment of the milk. Special deodorization processes are applied in milk plants (Figure 49).

After heat treatment and packaging, milk may absorb flavours, depending on the packaging material. Glass and tin are impermeable, but other materials like cardboard are permeable, although flavours differ widely in their penetrating power. To ensure protection against all possible flavour sources, containers must be made of impermeable materials. If such materials are very expensive or have other disadvantages, containers made from permeable material may be laminated with a very thin layer of an impermeable material (milk cartons), or combinations of various laminae may be used (plastic sachets).

Cooked flavour

This defect is caused by the heat treatment of milk. The intensity of the flavour mainly depends on the intensity of the time-temperature of the treatment and also on the extent to which the heating surface of pasteurizers or sterilizers is 'burnt on', and on the oxygen content of the milk. The cooked flavour principally results from heat-induced reactions of certain proteins of the milk, which liberate volatile sulphur-containing compounds. More intensive heating causes caramel-like substances to form from lactose. These reactions are greatly enhanced by the proteins. This causes a very distinct cooked or even burnt flavour, accompanied by a brownish colour. Consumers

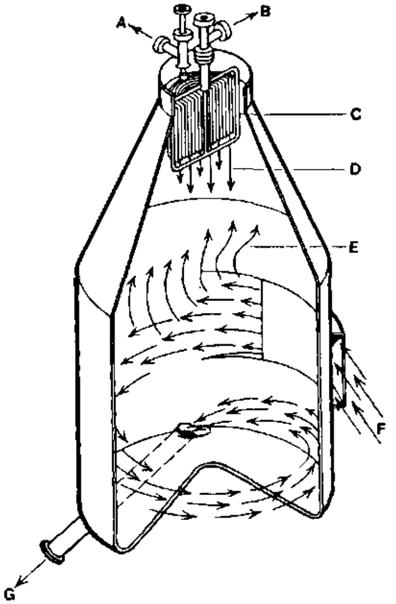

Fig. 49. Deaeration of milk. The product is pumped into the vessel (F), which is under a vacuum corresponding to a water-boiling point that is below the inlet temperature of the product. Vapours and gases rise to the top of the vessel (E). The gases are discharged through the top (A), as is the cooling water (B), whereas the vapours condense in the condensor (C) and drop back into the liquid product (D). After treatment, the product is discharged through the bottom outlet of the vessel (G). Courtesy: Alfa Laval Food Engineering AB.

accustomed to sterilized milk with a cooked flavour may reject normal HTST-pasteurized and UHT milk because of its bland flavour.

Products originating from sulphur-containing amino acids, the so-called free 'sulphydryl compounds', have an anti-oxidative action in milk and milk products. Sometimes, milk and milk products, such as cream for butter making, are heated to high temperatures to produce these 'natural anti-oxidants'.

Mild forms of cooked flavour may disappear after some time, probably because the responsible sulphuric compounds are oxidized. Cooked and very similar flavours developed in UHT milks may thus disappear after some time. The off-flavour is most persistent in UHT milk produced by direct steam injection, because this product has a lower oxygen content than the product produced by the indirect heating system.

Oxygen from the air which penetrates the packaging material of the milk will oxidize the sulphuric compounds and may – at a later stage – give rise to oxidized flavours.

Oxidized flavour

Oxidized flavour, also known as metallic, oily or tallowy flavour, develops in milk and milk products as a result of oxidation of the unsaturated fatty acids, especially those of the phospholipids. The defect is often mistaken for rancidity. The oxidation process is catalysed by some heavy metals, principally copper. Contamination of milk with copper on the farm and in the dairy plant must be rigorously avoided, since even very small traces (e.g. 10 ppm) have marked effects. Homogenization gives milk a certain protection against the development of oxidized flavours. The defect is also catalysed by exposure to light. In this case the flavour often develops several hours after the milk has been exposed. High-quality milk with a low bacterial count is particularly sensitive to this defect.

Milk, and milk products can be protected against this defect by:

- avoiding contamination from heavy metals, especially copper, on the farm and in the dairy plant;
- applying high pasteurization temperatures;
- adding antioxidants (N.B.: the use of antioxidants is prohibited or subject to restrictions in most countries);
- excluding oxygen;
- excluding light.

Coloured cartons and plastic sachets, or coloured – especially black – coatings or laminations (aluminium foil) in cartons or sachets will satisfactorily protect milk from light. Good results have also been obtained by using opaque plastic milk bottles.

However, exclusion of oxygen gives the best protection against oxidized flavour. Milk should be packaged or bottled in such a way that inclusion of air is avoided as much as possible.

Buttermilk, having a high phospholipid content, is very susceptible to the development of oxidized flavour.

Sunlight flavour

Sunlight flavour, sometimes called cabbage, burnt-protein or burnt-feather flavour, occurs in milk exposed to light. No direct sunlight is required, even light in cold stores will induce the defect, which is due to degradation products of proteins or amino acids. Oxidized and sunlight flavours often occur simultaneously and the two are often confused.

Homogenization is believed to make milk more susceptible to the sunlight flavour, but less susceptible to the oxidized flavour mentioned earlier. For complete protection against sunlight flavour, milk should be packaged in containers impermeable to light, as discussed under 'oxidized flavour'.

6.5.2 Sediment

A high cell content of milk or the use of reconstituted milk powder may be responsible for the formation of sediment in sterilized milk. Because of the lower heat stability of buffalo's milk, sediment in sterilized milk of this kind may develop more easily than in sterilized cow's milk. Milk powder with a poor solubility may also be responsible for sediment formation in pasteurized milk.

6.5.3 Bacteriological defects

In-bottle pasteurization

In-bottle or in-one-way package pasteurized milk usually deteriorates as a result of the development of thermoduric and spore-forming bacteria. Since psychrotrophic bacteria are generally killed by the pasteurization, the keeping quality of such milk under refrigeration may be expected to be good, although at temperatures as low as 7 °C (the average temperature in domestic refrigerators), certain strains of *Bacillus cereus* and some other proteolytic spore-formers, which survived pasteurization, may develop slowly. This may give rise to spoilage of the milk after one to two weeks, depending on the initial contamination of the milk.

At moderate temperatures of about 20 °C, milk may spoil as a result of the fast-growing *Bacillus cereus,* resulting in a bitter taste followed by sweet curdling of the milk. Storage at temperatures of about 30 °C and higher may also give rise to the development of proteolytic spore-formers like *Bacillus cereus* and *Bacillus subtilus,* although the conditions for the growth of *Streptococcus thermophilus* are favourable and acid coagulation of the milk is possible. In both cases, spoilage (sweet or acid curdling) is to be expected within one day, which means that this type of milk should be consumed on the same day it is produced or leaves cold storage.

HTST pasteurization

HTST pasteurized milk packed in bottles or one-way packages usually deteriorates as a result of recontamination. The kind of spoilage depends on the type of bacteria and the temperature at which the milk is kept. In pasteurized milk kept at low temperatures (about 7 °C) lipolytic and proteolytic psychrotrophic bacteria will generally develop, causing bitter, rancid or fruity tastes. Depending on the number of recontaminating bacteria, spoilage may be expected after 3 to 7 days.

At temperatures of about 15 °C and higher, large numbers of certain species will develop initially, but they will be overgrown by streptococci that produce lactic acid that makes the milk sour. This may occur within 24 hours.

Only in cases that milk is free or almost free of recontamination may a situation similar to in-bottle pasteurization occur.

The formation of a proper cream line in milk extends its keeping quality (Section 5.3). Some species, mainly *Bacillus cereus,* are responsible for the defect called bitty cream. In cream and in the cream layer of pasteurized milk, the fat-globule membranes are damaged by the enzyme lecithinase produced by this bacillus. This damage results in the formation of clumps of fat globules, preventing the cream layer being uniformly distributed in the milk upon shaking.

HTST pasteurization at temperatures higher than 72 to 73 °C and homogenization adversely affect the formation of a cream layer, as discussed in Section 5.3. Milk to be packed in plastic sachets is often homogenized to avoid the formation of a cream layer which would adhere to the plastic sachet.

Although the keeping quality of pasteurized milk at moderate temperatures (15 to

20 °C) is best if a moderate time-temperature pasteurization (e.g. 15 to 20 seconds at 72 °C) is chosen, higher temperatures may be preferred in the event of poor-quality raw milk, with the objective of destroying a larger number of bacteria, thus complying with legal standards. A higher pasteurization temperature will not improve the keeping quality. The time-temperature combination of pasteurization is of less importance for the keeping quality if the milk is stored at about 30 °C or even higher. In general, the keeping quality at these temperatures is extremely poor, and spoilage of the milk may be expected within 24 or even 12 hours, although the initial bacteriological quality of the milk plays some role.

In-bottle sterilization

The deterioration of in-bottle sterilized milk is the result of certain spore-forming bacteria that have survived the sterilization process. The most important species are the proteolytic *Bacillus subtilus* and *Bacillus circulans* and the acid-producing *Bacillus coagulans* and *Bacillus stearothermophilus* var. *calidolactis*. During storage at temperatures of 15 to 50 °C *B. subtilus, B. circulans* and *B. coagulans* may grow, causing a variety of defects after 2 to 4 days at 20 °C and 1 to 3 days at 30 °C. *B. calidolactis*, which produces the most heat-resistant spores, only grows at temperatures above 37 °C. It may cause milk to coagulate, even at temperatures of 50 to 70 °C.

Destruction of these bacilli depends on the rate of contamination, but generally a sterilization of 10 minutes, at 115 °C will be necessary to destroy *B. subtilus*, and 10 minutes at 120 °C to destroy *B. calidolactis*.

Leakage of the closure of bottles of sterilized milk will cause recontamination of the milk, resulting in spoilage that may be difficult to distinguish from spoilage caused by spore-formers, unless laboratory tests are carried out.

UHT sterilization

UHT sterilization of milk followed by aseptic packaging should give a sterile product. Flash sterilization of milk for 4 seconds at 142 to 145 °C will normally kill all bacteria and spores. Even under conditions that processing techniques are properly controlled, it may be found difficult to avoid a few packages per thousand becoming recontaminated. Recontamination usually results in a product with a keeping quality similar to that of recontaminated HTST pasteurized milk.

Milk proteinase (plasmin) is very heat-resistant. The rate of inactivation increases only slightly at temperatures above 110 °C, and even at 140 °C it will take at least 15 seconds to inactivate the enzyme. Therefore, UHT procedures to sterilize the milk by holding for only a few seconds at temperatures of 140 to 145 °C will be insufficient. After some weeks, active proteinases may cause a bitter taste in contaminated UHT-treated products, accompanied by a change to an opalescent appearance.

Lipases and proteinases produced by Gram-negative bacteria, especially those of the genus *Pseudomonas* are even more heat-resistant. The enzymes are even produced in deep-cooled milk by the psychrotrophic representatives of the group (water bacteria). They cannot be inactivated by normal UHT sterilization; they are even more resistant than plasmin. The bacterial lipases are responsible for the development of rancidity; the bacterial proteinases for the development of a bitter taste and occasionally gel formation. Since inactivation in UHT milk is not possible without materially impairing the taste and colour of the milk as a result of excessive heat treatment, prevention of the enzymatic spoilage must be tackled by improving the quality of the raw milk.

The bacterial enzymes are produced in significant quantities (Section 2.4), when the bacterial number has reached about 6 million bacteria per ml, that is at the end of the exponential growth (see Figure 7). This means that the enzymes need not be produced during handling and storage of milk at the farm, the collection centre or the dairy plant; the bacteria will generally not reach the stage of enzyme production, because they are either overgrown by lactic acid bacteria, or – in the case of deep-cooled milk – their development (even though it concerns psychrotrophic bacteria) is too slow. Production of the enzymes will only be possible in the case of excessive contamination, insufficient deep-cooling, or storage of the milk over very long periods. If contamination is severe and the temperature of cooling is just low enough to retard the development of lactic acid bacteria but does allow for a comparatively rapid development of Gram-negative bacteria, storage of milk for periods over 24 hours may involve a risk.

Bacterial enzymes can be expected to occur in raw milk as a result of contamination with fully-grown cultures. In such cultures, which may occur in insufficiently sanitized milking utensils like milk cans, storage tanks, etc., an accumulation of the enzymes may be found. Since the temperature of the utensils may be quite high between milkings (or in the case of storage tanks between storage periods), the Gram-negative bacterial flora may be expected to develop rapidly (provided they are not overgrown by lactic acid bacteria at the higher temperatures).

An accumulation of enzymes in the milk, as mentioned before, may make it unsuitable for the production of UHT milk, even if the total bacterial count of this milk is still comparatively low. Depending on the prevailing conditions, enzymatic spoilage of UHT milk is to be expected between a few weeks and several months after production. The phenomenon described may also make milk unsuitable for the manufacture of other UHT-sterilized products, such as evaporated milk and custards.

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7 Fermented milks

7.1 Origin of fermented milks

Contamination during milking and milk handling will result in a large variety of micro-organisms starting to develop after milk has been drawn. But in most cases – sooner or later – lactic acid bacteria (LAB) will become predominant by overgrowing the other bacteria. The acid produced is generally not considered unpleasant by the consumer and because it also suppresses pathogenic as well as proteolytic and lipolytic bacteria it actually helps to preserve milk. As it was almost impossible to prevent milk from becoming sour, even after boiling it, people became accustomed to the taste of the sour product and learned to appreciate it. This explains the habit of consuming fermented products in many countries and even the preference for these products. Moreover, the psychological aversion for fresh milk – being considered a product for infants and children – did not exist for these products. Most, if not all indigenous fermented products originated from the inability of the milk producer to control the keeping quality of fresh sweet milk.

Acid production causes the casein in milk to flocculate and the milk to attain a gel-like consistency. If left to stand, this gel may shrink, and liquid (whey) be expelled. This phenomenon is used in the production of certain types of cheese. However, syneresis – that is the above-mentioned shrinking – and whey expulsion are undesirable in the production of fermented liquid milk products, which must have a homogeneous structure.

From a comparison of the various fermented liquid milk products produced in the world it may be concluded that in spite of the numerous different names, all products can be classified in a few groups. The principal differences between these groups depend on:
- the type of milk used;
- the type of fermenting flora;
- the way the milk is processed either before or after fermentation.

Type of milk

Different kinds of milk give different kinds of products, even if they are incubated with the same type of fermenting flora under the same conditions. For example, yogurt produced from ewe's milk has not only a taste, but also a texture that differs from that of yogurt produced from cow's milk, even if the latter is enriched with milk powder to the same solids content. On the other hand, although certain fermented milk products were originally produced from the milk of a specific animal, nowadays, very similar products are made from milk of other animals. Thus, koumiss was originally made from mare's milk, but is at present made from cow's milk as well.

Fermenting flora

The flora that is found in indigenous fermented milk products largely depends on the ambient temperature and the character of the contaminating bacteria. Some LAB are mesophilic, others are thermophilic (see Table 11). The LAB can be characterized by the way they ferment lactose in milk after this disaccharide has been transformed into two monosaccharides, viz. glucose and galactose. Homofermentative LAB mainly produce lactic acid, whereas heterofermentative LAB also produce other products, e.g. carbon dioxide. Under certain conditions, some LAB are able to ferment citric acid into a number of products like carbon dioxide, acetic acid and diacetyl. Since diacetyl is an extremely important flavour compound in a number of dairy products, these bacteria are often named aroma bacteria.

In indigenous fermented milk products, mixtures of the various groups mentioned above are found. In areas with distinct seasonal variations in ambient temperature, changes in the composition of the microflora, and consequently in the properties of the product, are noticeable throughout the year. In many fermented products, the presence of specific micro-organisms other than LAB (e.g. alcohol-producing yeasts) may determine the character of the product.

To control fermentation processes, it is advisable to inoculate the fresh milk with

Table 11. Classification and character of lactic acid bacteria.

Family, species	Lactose fermentation	Mesophilic (M)/ Thermophilic (T)	Diacetyl-producing (D)
Streptococcaceae (cocci)			
Streptococcus cremoris	homofermentative	M	
Streptococcus lactis		M	
Streptococcus thermophilus		T	D
Streptococcus diacetylactis		M	D
Leuconostoc lactis	homofermentative	M	
Leuconostoc cremoris	heterofermentative	M	D
Lactobacillaceae (rods)			
Lactobacillus bulgaricus	homofermentative	T	D
Lactobacillus helveticus		T	
Lactobacillus acidophilus		T	
Lactobacillus	heterofermentative		

a culture specific for the product to be manufactured. Under primitive conditions of small-scale operation it is usually impossible to use pure cultures for fermentation. But fermentation can be controlled to a certain extent by inoculating every batch of fresh milk with a small quantity of the previously produced product. In this way the milk will be inoculated with a culture of virulent bacteria, which will start regenerating immediately, leaving little opportunity for the development of all sorts of undesirable micro-organisms. Inoculation will also occur if the utensils used for the manufacture of the product are not properly sanitized. The surviving bacteria left behind in the utensils will contaminate and consequently inoculate the fresh milk. However, improper sanitization will also result in the utensils gradually becoming dirtier, with the risk of the development of undesired acid-resistant micro-organisms, like yeasts and moulds.

Way the milk is processed either before or after fermentation
To control fermentation processes, milk should be intensively heat-treated before inoculation, with the aim of:
- destroying as many undesirable micro-organisms as possible;
- making the milk a more suitable nutrient for the bacteria responsible for the desired fermentation process;
- giving the final product certain specific properties, e.g. the desired viscosity.

Sometimes, milk is kept boiling for longer periods, so that some of the water evaporates and the milk proteins destabilize to a certain extent, thus contributing to an increased viscosity.

In all cases where cooling facilities are insufficient or unavailable, souring cannot be stopped at the desired acidity and the product may be too acid. Some of the serum of such a product can be drained off, thus diminishing the acid taste. The concentrated product thus obtained has lost some of the water-soluble nutrients.

In well-run milk plants, milk for the production of fermented milk products is always pasteurized – sometimes very intensively to obtain the results mentioned above – and then cooled to the required fermentation temperature before fermentation. After ripening, the product can be cooled to temperatures low enough to limit further growth of LAB, although the production of acid will not stop completely. The milk may be concentrated by evaporating some of the water under vacuum or by adding some milk powder. The milk is often homogenized, to increase the viscosity of the product.

The shelf-life of fermented liquid milk products can be extended, but this is not practised on a very large scale. The heat treatment of the acid product in combination with its high acidity improves the keeping quality considerably. To prevent whey separation in the acid milk product, special precautions have to be taken, such as decreasing the pH below 'normal', and avoiding fat contents below 1.50% and protein contents above 3.00%. Stabilizers may be added. Sometimes, fermented milks are preserved by the addition of preservatives; this procedure is prohibited in many countries.

In a number of countries, mixtures of fermented liquid milk products and water are popular beverages. In particular, yogurt-like products manufactured from ewe's milk are used for this purpose. Salt may be added. Other beverages are obtained by adding flavourings, fruits and sugar to the mixture of the fermented product and water.

Further reading

See Section 7.2

7.2 Cultures and starters

7.2.1 Flora of cultures and starters

In the production process of fermented dairy products, inoculations with a small quantity of the desired fermenting flora, named culture, take place. Since the culture initiates or starts fermentation, it is often referred to as a starter (especially in the production of butter and cheese).

The most important organisms in starters and cultures are the homofermentative and heterofermentative LAB, which can be classified into two families according to the scheme in Table 11, which shows the most important bacteria found in starters and cultures (see also Section 2.4).

Cultures and starters can be classified into two groups, according to the characteristics of the micro-organisms; mesophilic and thermophilic. These groups do overlap to some extent, however.

Mesophilic starters and cultures are used at temperatures varying between 16 and 30 °C. They contain mesophilic organisms. The most typical representatives are the homofermentative *Streptococcus cremoris* and *Streptococcus lactis*, which are similar, although the latter is able to produce free amino acids, which are believed to stimulate the growth of the *S. cremoris* strains. Another important species in mesophilic starters is the homofermentative *Streptococcus diacetylactis*, which is able to produce lactic acid and in the presence of lactose to ferment citric acid into a number of other compounds such as carbon dioxide and diacetyl. However, at a pH below 5, carbon dioxide and a number of compounds similar to diacetyl, but non-aromatic, are produced.

The heterofermentative *Leuconostoc cremoris* (also named *Betacoccus cremoris* or *Leuconostoc citrovorum*) is also able to ferment citric acid into carbon dioxide, diacetyl and some other products. Unfortunately, the leuconostocs may reduce diacetyl into non-aromatic compounds again. The intensity of reduction varies between the various representatives of the strains. *Leuconostoc lactis* and *Leuconostoc cremoris* produce a little acid only. Other bacteria like *S. lactis* and *S. cremoris* must produce sufficient acid before Leuconostoc cremoris will be able to produce diacetyl.

Streptococcus thermophilus is homofermentative and is especially found in thermophilic starters and cultures, that are particularly suitable for products cultured at comparatively high temperatures, such as yogurt and certain cheese varieties where the curd is cooked at elevated temperatures.

Heterofermentative LAB are also important in cheese starters where the production of carbon dioxide contributes to the eye formation as in Edam and Gouda cheese, or where it gives the cheese an open structure important for the development of moulds in blue-veined varieties of cheese. Diacetyl-producing LAB are also believed to contribute to the flavour of various cheeses. Gas-producing LAB must be absent in starters used for the production of cheese varieties with a so-called 'closed texture'.

Several lactobacilli prefer increased temperatures (above 30 °C). They are of special importance in the production of a number of fermented liquid milk products. Various species are known for the production of large quantities of lactic acid. They are sometimes wrongly reckoned among the streptococci. In general, they produce lactic acid rather slowly. They are often found in combination with other bacteria, mainly lactic acid streptococci, which produce lactic acid much faster and which stimulate the growth of the lactobacilli.

Lactobacillus bulgaricus which, together with *S. thermophilus*, is essential in yogurt cultures, is known for its capacity to produce the flavour component acetaldehyde in addition to diacetyl. *Lactobacillus helveticus* contributes to the flavour development in Swiss cheese. Like *L. bulgaricus* it is found in starters and cultures together with *S. thermophilus*. *Lactobacillus acidophilus* is a slow acid producer in cultures used for the production of acidophilus milk. This product has a plain acid flavour, and may be combined with other bacteria to obtain a more palatable product. Acidophilus milk is recommended as a dietary product, because *L. acidophilus* functions in the large intestine of man (see also Section 7.3.2).

Other micro-organisms found in cultures and starters, but which are not LAB, are varieties of propionibacteria and yeasts. Propionic acid bacteria are responsible for the formation of the characteristic eyes in Emmental (Switzerland) and Gruyère cheese. They are a normal component of the starters used in the manufacture of these cheeses and produce propionic acid, acetic acid and carbon dioxide, thus contributing to gas and flavour production.

Yeasts are a contaminant if present in most starters and cultures. Some are essential in cultures used for the production of alcoholic fermented milks.

Many more micro-organisms other than those discussed in this chapter are found in cultures for the production of cheeses and fermented liquid milk products, either as a component that really contributes to the desired fermentation processes, or as an 'incidental' component of the flora.

7.2.2 Production and availability of cultures and starters

Starters and cultures can be composed 'scientifically' by specialized laboratories. There may be single- or multiple-strain starters. Single-strain starters contain only one strain of LAB. They have the disadvantage of not being resistant to the attack of a bacteriophage specific for that particular strain (see Section 7.2.3). Nevertheless, single-strain starters may be used if the particular characteristics of one specific strain are needed in a production process; for example, the use of single-strain starters of non-gas-producing rapidly growing LAB in the industrial production of Cheddar cheese. The species and strains included in starters and cultures are chosen according to the type of product to be produced and the production method to be followed.

Some dairy plants use the same starter or culture for many years and only decide to replace it when results become less satisfactory. Other plants replace their starters and cultures at regular intervals as a precaution against failure that may result from a loss of the original characteristics. Such a loss may be caused by:

- the occurrence of bacteriophages;
- contamination by other micro-organisms;
- changes in the ratios of the various species and strains. (This usually results from the system of subculturing, which allows for an enrichment with and an ultimate dominance of particular species or strains. It usually leads to a change of the characteristics of the starter or the culture, or may take them more sensitive to phage attack.)

There are several ways of obtaining starters and cultures:

- From specialized firms. In this case the starters and cultures are generally freeze-dried.
- From institutions. In this case the starters or cultures may be freeze-dried or fresh.
- From other dairy plants. In this case, the starters or cultures are usually fresh.
- By production from fresh raw milk.

Commercial starters and cultures have the advantage that species and strains that fit the particular requirements of the plant can be chosen. As a result of freezing, drying and storage, commercial cultures and starters have often lost their virulence. In this case it will be necessary to re-inoculate and incubate several times to restore the original virulency before they are used for processing.

If starters cannot be obtained easily, it is possible to cultivate simple lactic-acid starters from raw milk. Fresh raw milk is stored at ambient temperature until it has developed sufficient acid to curdle. At that moment, fresh milk is boiled for at least 5 minutes and cooled to the temperature at which the milk will usually be fermented in the production process. The top layer of the available sour milk is skimmed with a ladle to remove aerobic micro-organisms. Thereafter, a small quantity of the sour milk is added to the boiled milk (e.g. 2 to 3%), after which the milk and the inoculum are thoroughly mixed by stirring. After 24 hours incubation, a fresh quantity of boiled milk is inoculated with a small quantity of the second lot of sour milk, for incubation under the same precautions. This procedure is repeated daily for about one week using sterilized equipment. Inoculation and incubation of the milk will take place in a bottle, which must be closed with a sterilized stopper. The equipment can be 'sterilized' by immersing spoons, ladles, bottles and stoppers in boiling water for at least 10 minutes. During the period of daily transference, the percentage of the daily inoculation should be adjusted in such a way that the coagulated sour milk has a pleasant acid flavour at the moment it must be used. After this period of cultivation, the sour milk can be used as a starter, because the LAB will have overgrown other bacteria almost completely.

7.2.3 Low-activity cultures and starters

If a starter does not produce acid in a product at the same rate as it did initially, its activity is said to be low. In extreme cases, acid production stops completely or almost completely, and the starter is inactive. There are a number of causes of low activity, such as irregularities in inoculation percentage, incubation temperature and/or in incubation period. However, in most cases low activity is caused by growth-inhibiting agents, such as antibiotics, sanitizing compounds, preservatives and bacteriophages.

Antibiotics

These compounds are excreted in the milk of animals treated with an antibiotic. Milk from such animals should not be supplied to the dairy plant for a couple of days after treatment. The actual time depends on the way the antibiotic is administered, but 3 to 5 days is sufficient in most cases (Section 2.2). Natural inhibiting agents in milk may influence bacterial development (Section 2.4). Such agents are inactivated during normal pasteurization.

Sanitizing agents

Sanitizing agents such as chlorine, iodine and quaternary ammonium compounds may retard the development of lactic acid bacteria. At the level at which these agents are active, they already affect the taste and flavour of the milk (Section 2.2).

Preservatives

Preservatives may be added to milk to enhance its keeping quality. Hydrogen peroxide is the most familiar one. It is destroyed by heat treatment (Section 2.2).

Bacteriophages

Phage activity. Although bacteriophages have much in common with micro-organisms, they are characterized by a number of distinct differences. Like micro-organisms, they can be destroyed by heat, UV-radiation and disinfectants. They do not occur in the form of individual cells, but as small particles, which contain proteins. Unlike bacteria, they do not possess a metabolic system. Consequently, in order to multiply they depend on the metabolism of a host bacterium. In other words: the bacterium itself produces the phages. It thereby kills itself. Bacteriophages attack bacteria by attaching themselves to the bacterial cell and then penetrating it, after which they can multiply. Ultimately, the bacterial cell bursts, thus liberating all phages produced.

Phage activity builds up gradually. After a starter has been contaminated, acid formation may appear fairly normal for some time, although the LAB are attacked by the phage and consequently produce less acid. But the quantity of acid may still be enough to reach the level required in the particular production process. The actual problem arises at the moment that enough acid can no longer be produced. At this moment the activity of the phage is noticeable. This situation generally occurs suddenly and seriously disrupts the normal production process.

There are numerous different strains of phages. Each is characteristic to one strain or to a number of very closely related strains of bacteria. On the other hand, a bacterium may be susceptible to a number of totally different phages.

Phage control. Measures for phage control are to a large extent similar to those taken to control contamination with and development of micro-organisms. Small quantities of milk or starters in small localities or rooms are easier to protect against phage infection than are large quantities in large production areas. It is therefore advisable to keep mother cultures for the daily inoculation of the bulk quantity of milk, instead of using a small quantity of the previous day's production (Figure 50). Moreover, a stock culture may be kept in the laboratory of the dairy plant. This stock culture can be used as an inoculum for the mother culture if the quality of the latter deteriorates. An even better strategy is to keep a number of different stock cultures, so that a switch can be made to another culture if the culture in use has become inactive.

The production of mother and bulk cultures should take place in a separate room not directly connected with the processing localities. All equipment, especially the equipment used for the production of starters and cultures, must be sanitized properly, including a daily sterilization with solutions containing 150-300 ppm active chlorine

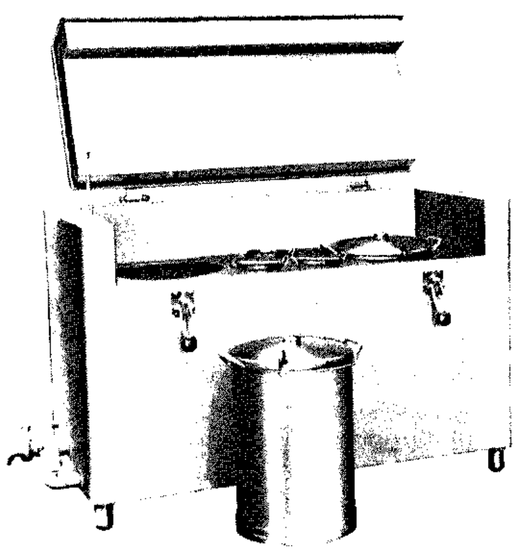

Fig. 50. Heater and incubator for starters. Three small vats in the centre for mother starters, flanked by two larger vats for bulk starters. Courtesy: Pasilac AS.

or solutions of other products of comparable strength. It may be found useful to spray localities used in the production process with a sanitizer once or twice a week.

However, it is essential to apply preventive measures too, so that dairy products will not become infected with phages directly or indirectly. *Milk pasteurization must be* very thorough, to destroy all phages. Generally, pasteurization procedures practised in the production of starters, cultures and fermented milk are sufficiently intensive. Reconstituted skimmed milk powder of good quality may be preferred over fresh milk. Sometimes, special dry media, low in calcium and high in phosphate content are applied for the production of starters and cultures, because calcium deficiency suppresses phage development. Special equipment has been developed to enhance protection against phage invasion.

Since all phages show affinity for certain bacteria, multiple-strain starters will be found far less susceptible to phage infection than single-strain starters. Multiple-strain starters are usually only inactivated by severe infections. Such starters have the ability to recover. However, by then the damage to the dairy plant has already been done.

To avoid phage infection in cheesemaking, the whey must not be kept in the cheesemaking localities, because whey is an imporant carrier of bacteriophages. It should be removed from these localities immediately after separation of the whey-curd mixture. Dairy effluents may be severely contaminated with phages. To avoid airborne contaminations, installations for the treatment of dairy effluents must not be sited close to the dairy plant.

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See also 'Further reading' Section 7.3

7.3 Types of fermented milk

The International Dairy Federation (IDF) defines fermented milks as products prepared from milks (whole, partly or fully skimmed milk, concentrated milk, or milk reconstituted from partly or fully skimmed milk powder) homogenized or not, pasteurized or sterilized and fermented by specific micro-organisms. The most important fermented milks will be discussed below.

7.3.1 Bulgarian milk

A typical example of a once popular sour milk is Bulgarian milk, often named Bulgarian buttermilk, although it is not produced by churning milk or cream. The good health of the Balkan people has been attributed to the consumption of this product. The fermenting bacteria – *Lactobacillus bulgaricus* – were supposed to pass the human stomach and to suppress toxin-producing organisms in the lower intestine.

The indigenous product is a harsh, very acid milk. It may reach an acidity of 300 to 400 °D. As a result of the high acidity of the final product, other organisms are easily suppressed and a very pure culture of *Lactobacillus bulgaricus* is the result.

Because of its supposed therapeutic value, the consumption and consequently the industrial production of Bulgarian milk became popular in many countries, but this popularity decreased dramatically when the ability of the lactobacilli to pass through the stomach was questioned. However, many people still believe that enzymes produced by these bacilli and by other LAB are able to pass through the stomach. Such enzymes may play a beneficial role in the digestive tract.

Industrial production of Bulgarian milk

Bulgarian milk is manufactured from pasteurized standardized or skimmed milk. After the temperature has been brought to 40 to 45 °C, the milk is inoculated with 2 to 3% of a culture of *Lactobacillus bulgaricus*. The milk is then incubated at about 40 °C until it has reached the desired acidity, which will take about 12 hours. At that moment it is stirred and cooled to a temperature below 10 °C to prevent further acid production. After cooling, the milk is bottled and put in cold store. Since bulk cooling may take much time, it is also possible to bottle the acid product as soon as it has been stirred until smooth, and to continue cooling in cold store.

In general, an acidity no higher than 125 to 150 °D is desired. The firmness or viscosity of the product depends on consumer preference. Intensive heat treatment of the milk, for instance at 90 °C for 30 minutes, and homogenization both increase the viscosity. To smooth the taste of the product and to improve its flavour, it may be mixed with cultured buttermilk.

A special yogurt cooler may be used to cool the in-bulk ripened product. A tubular cooler with wide tubes is usually used, but plate coolers with a larger than normal distance between the plates can also be used.

7.3.2 Acidophilus milk

Acidophilus milk is a fermented milk manufactured by the development of *Lactobacillus acidophilus*. It has superseded Bulgarian milk to a large extent. It has the same therapeutic value that was attributed to Bulgarian milk, but acidophilus bacteria are able to pass through the stomach and do occur in the intestine of man espcially in the intestine of the human infant. The bacilli are easily supplanted by other microorganisms after weaning. If the flora is to be maintained, it is necessary to consume acidophilus milk regularly.

The acid flavour is not generally liked, so combinations of the lactobacilli and other lactose-fermenting bacteria have been introduced to obtain a more palatable product. However, acidophilus bacteria are easily lost in combinations with other bacteria, because they develop rather slowly and are soon overgrown. It is difficult to maintain pure cultures, for the same reason.

Industrial production of acidophilus milk

Mother cultures must be incubated with great care. After inoculation of 0.2 to 0.3% of a pure acidophilus culture in sterilized milk, incubation takes place at 38 °C until the milk coagulates; this takes 12 to 18 hours. Immediately thereafter, the product is cooled to 4 °C and stored at this temperature. It is advisable to transfer the mother culture every other day.

Standardized or skimmed milk can be used for the industrial production of acidophilus milk. The milk should be homogenized and intensively heat-treated before incubation. It is sufficient to pasteurize high-quality milk at 90 to 95 °C for a few minutes. After heat treatment the milk is cooled to 38 °C and inoculated with about 2% of an acidophilus culture. It is incubated until an acidity of approximately 80 °D has been reached. The product is cooled and stirred until smooth, after which it is packaged and put in cold store. The product is either cooled in bulk until a sufficiently low temperature is reached, or cooling is stopped after the product has been stirred to smooth, then the product is packaged and the cooling subsequently continues in cold store.

7.3.3 Alcohol-fermented milks; kefir and koumiss

Kefir

Kefir products are far less widespread than yogurt-like products. Kefir originates from the Caucasian mountains, where it is produced in a cool climate. The milk of various species of mammals can be used.

The inoculum consists of white clusters of grains containing casein and a variety of micro-organisms. The main organisms are lactose-fermenting bacteria and *Torula* and *Saccharomyces* yeasts. The most important lactose-fermenting bacteria are *Lactobacillus* and *Leuconostoc* species, but *Streptococcus lactis* and other LAB are also found. The *Torula* yeasts are unable to ferment lactose, but *Lactobacillus caucasicus* hydrolyses lactose into galactose and glucose which can be fermented by this yeast. Other micro-organisms may be present in kefir grains as the result of contaminations; this can be harmful to the quality of the product. It is believed that several investigators have given different names to the same or similar microbes.

The main products produced by the kefir grains are lactic acid, carbon dioxide, alcohol, diacetyl and acetaldehyde, together with degradation products of proteins. A slime-producing bacillus is responsible for the firm texture of the grains. A proper ratio between lactic acid and alcohol is important for the quality of the product, but no uniform standard can be given, because of differences in consumer preference. The acidity may vary between 70 and 100 °D, and the alcohol content between 0.5 and 1.5%.

In indigenous production, milk in earthenware pots, leather bags or other receptacles is inoculated with the grains. Fermentation usually takes place at temperatures between 10 and 20 °C, depending on the ambient temperature. During daytime, milk can be put in the sun to increase its temperature. After a couple of days, the product is ready for consumption. The grains removed from the kefir can be used to inoculate the next production.

Industrial production of kefir

Dried kefir grains are commercially available. Before they can be used for the production of kefir they must be activated by soaking them in lukewarm water for a couple of hours, followed by repeated cultivation in pasteurized milk until all grains are swollen. At that moment the culture is ready for use.

A mother culture can be kept by inoculating 1 l of intensively pasteurized milk with about 200 g of kefir grains and incubating the liquid at 20 °C for 24 hours. Thereafter, the culture is cooled and stored at a temperature below 7 °C. It is advisable to transfer the culture at regular intervals. Before every transference the grains should be washed in boiled water.

Standardized or skimmed milk is used for the production of kefir. The milk may be enriched with milk powder. Before inoculation, the milk should be properly homogenized and pasteurized. The time-temperature combination of pasteurization depends on the desired texture of the product, as in the manufacture of other fermented milks. After pasteurization, the milk is cooled to the cultivation temperature, which may vary from 15 to 30 °C, and inoculated with 3 to 8% of moist kefir grains. The milk is incubated until a soft and smooth coagulum is formed; this takes 8 to 12 hours. It is advisable to stir the liquid several times during fermentation. After incubation the grains are removed by straining the liquid through a stainless-steel sieve. The filtered liquid is bottled in strong narrow-mouthed bottles, which are closed tightly with crown corks. Then the product undergoes an additional fermentation at a much lower temperature, for instance at 5 to 10 °C, for 24 hours.

Lactic acid production takes place during the first step of incubation. During the second step, LAB hardly develop, but conditions for the production of alcohol and carbon dioxide are very good. The organoleptic quality of the product is controlled by the time-temperature combination of the two steps. A final acidity of the product of about 90 °D is generally considered to be satisfactory. Prolonged fermentation in the second step will result in a higher alcohol and gas content.

Kefir milk

The filtrate obtained after sieving off the grains can be used for consumption, but in large-scale industrial production it is used as a bulk culture for the inoculation of milk in the manufacture of kefir milk. Cultivation takes place in two steps; the first step at an average temperature of about 20 °C and the second step at about 10 to 15 °C. Kefir milk generally has a lower alcohol content than kefir.

Koumiss

Koumiss is an alcoholic sour milk drink originating from Russia. It is similar to kefir. Originally, it was exclusively manufactured from mare's milk. The product is attributed to have therapeutic value for treating tuberculosis. Some investigators attribute its value to specific (antibiotic) compounds produced during fermentation, whereas others value the product because mare's milk is very similar to mother's milk. It forms a soft curd and has a high vitamin C content.

The culture for the manufacture of koumiss consists of a variety of microorganisms, but most important are *Lactobacillus bulgaricus*, *Streptococcus thermophilus* and *Torula* yeasts. *L. bulgaricus* and *S. thermophilus* are able to produce large quantities of acid; *Torula* yeasts produce alcohol, carbon dioxide and flavour compounds. The indigenous product has an acidity of up to 120 to 150 °D and an alcohol content of up to 2.5%.

Insufficient mare's milk is available for the industrial production of koumiss, and mixtures of mare's and cow's milk or pure cow's milk are used as an alternative. To compensate for the lower lactose content and the higher protein content in cow's milk, whey or sugar and water may be added.

A large number of manufacturing procedures have been developed and some have been patented. They will be outlined below.

Industrial production of koumiss

The culture to be used for the inoculation of the milk is prepared by mixing a culture of yogurt bacteria or *Lactobacillus bulgaricus* and a culture of *Torula* and/or *Saccharomyces* yeasts. Pasteurized cow's milk – if desired, modified – is inoculated with 10% of the mixed culture and incubated at 27 °C until the acidity reaches about 80 °D. At this moment a firm curd should have been formed, which is kept under intermittent aeration and is stirred to stimulate yeast development. After several hours, when the acidity has increased to 90 °D, the product is bottled, hermetically sealed and kept at 17 °C for another 2 hours to allow for more alcohol and carbon dioxide to be produced. Then the product is cooled to 4 to 5 °C and stored until distribution.

Strong narrow-mouthed bottles with a crown cork closure are required to withstand the high pressure that will develop in the bottle as a result of the carbon dioxide production.

Other methods recommend a two-step operation. First, a lactic acid producing culture is added to the modified cow's milk, which is incubated at 35 to 37 °C for 4 to 8 hours until the acidity is about 55 °D. At this point the second step starts with cooling the product to 25 to 30 °C and adding yeasts for further – in this case 'in bottle' – fermentation, which may take another 24 to 48 hours.

7.3.4 Buttermilk

Buttermilk is a by-product of butter making and should be considered as such. Poor-quality milk or cream will result in poor-quality butter, but if this butter is used for ghee production (Section 8.5) an acceptable product that satisfies local taste may be obtained. The buttermilk, however, will be of inferior quality. This is especially the case if cream that has been collected over a number of days without proper cooling is churned. The poor quality is due to the activity of putrefying organisms that develop before acidification, and the development of yeasts and moulds that thrive in the sour product.

Too often, buttermilk goes to waste as a result of its poor quality. Sometimes, buttermilk is drained and part of the serum – containing most of the off-flavours – is removed. In this way, the proteins, which form the most nutritional part of the buttermilk, are collected for human consumption. The drained curd may be consumed fresh or be preserved by drying (Section 9.2). Hygienic conditions of milk production and handling, proper cooling of the milk or cream and inoculation with a culture of LAB will considerably improve the quality of the buttermilk.

The nature of the starter used for inoculation under indigenous conditions of butter making will mainly depend on the ambient temperature. In cooler areas, the starter will principally contain mesophilic LAB, whereas in warmer climates, yogurt-like bacteria will be found. In most cases, however, no special starter will be used, and acidification depends on 'spontaneous contamination' of the fresh milk or on the milk being inoculated with a small quantity of the previous day's production.

Industrial production of buttermilk

Under conditions of hygienic milk production and handling, and properly controlled industrial processing, a high-quality buttermilk can be produced by churning sour milk or cream. This product is highly esteemed in many parts of the world. If the butter making process does not provide sufficient buttermilk to meet demand, a similar product can be manufactured by fermenting skimmed or standardized milk, making use of a buttermilk starter. This artificial buttermilk is usually named 'cultured buttermilk'.

Natural buttermilk

Since butter is the most valuable product of butter making, the process of handling and churning cream (or milk) is directed to enhancing the quality of the butter, whereas the properties of the buttermilk have to be taken as they are. Fortunately, many of the procedures directed to the production of high-quality butter with a prolonged keeping quality – also in cold store – also benefit the quality of the buttermilk.

The buttermilk as it is after churning should be handled with much care to maintain its quality. It must be cooled as quickly as possible to stop further acid production. An acidity of about 85 to 95 °D is to be preferred. The comparatively low acidity, together with the butter flavour and the small quantity of fat (on average about 0.5%), are the factors responsible for the pleasant mild flavour and taste of buttermilk.

Every effort should be made to prevent serum separation or 'wheying-off'. This is considered to be the most serious texture defect of buttermilk. Three kinds of wheying-off can be distinguished:

- surface separation: the proteins settle in the lower part of the liquid, leaving a top layer of whey;
- bottom separation: the proteins rise in the liquid, forming a lower layer of whey;
- middle separation: some of the proteins settle, whereas the rest rise, leaving a layer of whey in between.

In good-quality buttermilk, all serum is 'absorbed' by the casein particles and the liquid has a homogeneous appearance. If not all the serum is absorbed, the casein-serum balance is disturbed and free serum will separate. Since the density of the protein is higher than that of the serum, the former will settle, leaving a top layer of whey. To prevent surface separation, the addition of water during butter making (Section 8.3) should be limited. Furthermore, excessive heat treatment and too low an acidity of the milk or the cream, as well as storage of the buttermilk at a temperature higher than 10 °C, will increase the risk of the defect.

In the event of bottom separation, small bubbles of gas, either carbon dioxide or air, adhere to the surface of the casein particles, which makes them rise in the liquid. Carbon dioxide is a fermentation product and is linked with the acidification of the milk or cream. Air is beaten into the cream during churning. It is difficult to avoid the presence of these gases in fresh buttermilk. Storing the buttermilk some time before packaging will allow the gases to escape, especially if the milk is stirred very gently, preferably before cooling. But in this case, an unacceptable increase in acidity as a result of postponement of cooling must be avoided. Care should be taken that no air is introduced into the buttermilk as a result of pumping and of leaks in pipelines, or during bottling. Positive types of pumps are recommended.

Middle separation is the result of a combination of surface and bottom separation.

Oxidized flavour is a defect that develops easily in buttermilk. The high phospholipid content of the product contributes considerably to this defect. Consequently, the problem increases with the fat content of the cream. Care should be taken to avoid the product being contaminated with copper or exposed to light.

Cultured buttermilk

Cultured buttermilk is produced by fermenting skimmed milk with a culture of bacteria that produce lactic acid and diacetyl. Starters used for butter production are often used.

Unlike natural buttermilk, the cultured product is almost free from fats and phospholipids; this has a marked influence on its quality. The flavour is sharper and rather flat, but the addition of some cream to the skimmed milk to increase the fat content to about 0.5% tends to improve the quality. Sometimes a little salt, e.g. 0.1%, is added, to accentuate the flavour. As a result of the absence of phospholipids the product is not subject to oxidative defects.

The product is manufactured by inoculating about 1% of a starter and incubating at 21 °C. At the moment the acidity has reached 90 °D, which will take about 15 hours, the product must be cooled immediately below 15 °C. During cooling, the curd is stirred gently.

To prevent wheying-off, similar precautions have to be taken as in the case of natural buttermilk.

7.3.5 Yogurt and yogurt-like products

The indigenous yogurts are mainly manufactured in the Middle East and in other countries around the Eastern part of the Mediterranean. They are known under names such as mast (Iran), leben or laban (Iraq, Lebanon, Egypt), zabade (Sudan), yoğurt (Turkey). A similar yogurt-like product is known as dahi in India. In many cases, yogurts are actually milks that have become sour as a result of contamination during milking and milk handling.

Yogurt may be manufactured from ewe's, goat's, buffalo's or cow's milk or from mixtures, with a strong preference for ewe's milk in many countries of the Middle East. Ewe's milk yogurt has a special flavour and a particularly firm consistency, which makes it an intermediate product between fermented milk and fresh soft cheese. Since ewe's milk is only produced during part of the year, this milk is sometimes stored deep-frozen to make it available throughout the year.

The method of manufacture and the composition of the cultures used for the fermentation of the milk vary from area to area.

Milk may be used raw or may be heat-treated before processing. Sometimes, the milk is boiled for periods up to an hour. After boiling, the milk is cooled to 30 to 40 °C and inoculated with a small quantity of the previous day's production. Sometimes, one relies on 'spontaneous acidification'. After stirring, the milk is allowed to ferment. The time of fermentation depends on the temperature, the percentage of inoculation and the type of the culture. The percentage may vary from 0.5 to 5.0%, but usually the lower percentage is applied. Under indigenous conditions the temperature of fermentation largely depends on the ambient temperature, whereas the composition of the culture adjusts itself to the fermentation temperature. At the higher temperatures the typical yogurt bacteria (*Streptococcus thermophilus* and *Lactobacillus bulgaricus*) will develop, whereas at the lower temperatures the mesophilic lactic acid bacteria will predominate. This explains regional and seasonal differences in yogurt-like products. Sometimes, yeasts and moulds are also found.

Lactobacillus bulgaricus is responsible for the development of a typical flavour, mainly consisting of acetaldehyde. A sour product with this flavour and a firm consistency is the main characteristic of the category of yogurt-like products. The yogurt bacteria also produce diacetyl. The growth of some *Leuconostoc* species may also contribute to the production of diacetyl.

All the products obtained by fermenting mixtures of thermophilic and mesophilic cultures belong to the yogurt-like products. The name 'yogurt' should be preserved for products manufactured by cultures consisting exclusively of *Streptococcus thermophilus* and *Lactobacillus bulgaricus.*

Under primitive conditions of manufacture of yogurt-like products, there are few possibilities for cooling the product when it has reached the required acidity and obtained its characteristic flavour. Over-ripening may give the product a less pleasant acid taste. The acid taste can be reduced by diluting the yogurt or by draining off some of the whey.

Yogurt and yogurt-like products are often given various names, which easily leads to confusion. The word 'yogurt' should only be used for the product manufactured from milk, the solids content of which may be slightly increased to improve the body of the product. This type of yogurt is sometimes called 'plain yogurt' or 'cultured yogurt' as well. Yogurt-like products with a substantially increased or decreased solids-non-fat content should be designated by their special name or by the word 'yogurt' in combination with an adjective indicating the nature of the product. Flavoured yogurt, or yogurts containing fruit or fruit juices should be given the name 'yogurt' in combination with the name of the flavour, the fruit or the juice that has been added.

Industrial yogurt production

Culture. Industrial produced yogurt is a fermented liquid milk product resulting from the symbiotic growth of *Streptococcus thermophilus* (cocci) and *Lactobacillus bulgaricus* (rods) in milk at a temperature between 30 and 45 °C, depending on the type of yogurt and the culture used. The optimum growth conditions of the two types of yogurt bacteria differ slightly. The optimum temperature of the cocci is a few degrees Celsius lower than that of the rods and their optimum pH is slightly higher. Since a 1:1 ratio between cocci and rods in the cultures is ideal for the development of a proper flavour and consistency, some investigators recommend cultivating separate master cultures of the streptococci and the lactobacilli and mixing the two to produce a new mother culture in case the optimum ratio cannot be maintained or the quality of the culture deteriorates for other reasons. To cultivate the master cultures separately, pasteurized or sterilized milk should be inoculated with 0.1 to 1.0% inoculum. However, the cocci should be cultivated at 37 to 40 °C and the rods about 3 to 5 °C higher. After incubation, the cultures should be cooled to 4 to 5 °C.

Immediately after the milk has been inoculated with a yogurt culture, the streptococci start developing fast, whereas the growth of the lactobacilli lags behind, until further development of the cocci is hampered by the acid produced. From this moment on the lactobacilli will show an improved activity until the original balance between the two is restored. At that moment the product must be cooled. If both bacteria are not cultured separately, the balance is best maintained at an incubation temperature of 43 to 45 °C, an inoculum of 1.0 to 2.5% and a final acidity of 80 to 100 °D. Lower temperatures and larger inoculum doses will stimulate the development of the cocci. The rods are stimulated by the fermentation process continuing beyond the recommended acidity.

Mother cultures of yogurt may be cultivated in bottles or in small metal vats, depending on the quantity required to inoculate the bulk culture. The bottles or vats are filled with intensively pasteurized or sterilized fresh or reconstituted milk and then repasteurized in a water bath at 90 °C for 5 to 10 minutes, although sometimes for much longer. After the milk has been cooled to about 45 °C, 2.5% inoculum is mixed through it. The milk is incubated at this temperature until the acidity has reached 80 to 85 °D. At this moment the milk is cooled to below 5 °C as quickly as possible, and stored at this temperature if the culture is not used immediately. During cooling the acidity may rise another 5 °D. Bulk cultures are cultivated in a similar way.

Production process. Yogurt is produced from whole, skimmed or partly skimmed milk. In areas where milk supply is short, reconstituted or recombined milk may be used, but even if the quality of the milk powder and the butter-oil is excellent, the flavour of the yogurt will be improved if 25% or more fresh milk is added.

The pretreatment of milk before inoculation is directed to the production of yogurt of a firm consistency, which will not show any sign of wheying-off. Yogurt manufactured from ewe's milk, and to a lesser extent from buffalo's milk, will have a firmer consistency than yogurt made from cow's or goat's milk. Depending on the facilities available in the dairy plant, the following measures can be taken to obtain yogurt with the desired firm consistency if cow's or goat's milk is used:

- homogenization of the milk at about 55 °C at a pressure of about 200 atm. Higher temperatures, e.g. 65 °C, and lower pressures, e.g. 150 to 200 atm, are sometimes used,
- intensive heat treatment of milk, which may vary from batch pasteurization at 85 to 90 °C for half an hour, to flow pasteurization at the same temperature, or sterilization for 5 minutes at a temperature of up to 120 °C,
- addition of 2 to 3% skimmed milk powder to increase the solids content of the product,
- addition of 'thickening agents'.

A combination of the methods described above may be applied.

After homogenization and pasteurization, the milk is cooled to 45 °C and inoculated with 2.5% of a bulk culture. After thoroughly mixing by stirring, the milk is put into bottles, pots, cups or other containers and incubated in a water bath at 45 °C, until the required acidity and firmness have been reached; this will take about 2 to 2.5 hours. Thereafter, the product will be refrigerated. During refrigeration the development and acid production of the lactobacilli will continue for a while. Cooling of the product should start at the moment that a final acidity of about 90 °D is reached. The exact acidity at which refrigeration should start depends among other factors on the cooling system and its efficiency. Cooling may take place in a water bath by circulation of cold water, or in cold store by forced circulation of cold air.

The production method described will give a product with a firm consistency – called solid or set yogurt – but requires much space and labour. Therefore, the production of a product similar to yogurt, called stirred yogurt (generally marketed under the name 'yogurt'), has been introduced. In this case, the product is packed after fermentation, instead of before fermentation. Several procedures for the production of stirred yogurt have been tried, but a number of problems have been encountered, leading to defects such as wheying-off, high acidity, low viscosity and insufficient firmness. Satisfactory results have been achieved by the introduction of a special culture containing slime-producing yogurt bacteria, which give the product a heavy viscous consistency. A small dose of inoculum (about 0.25‰) and a low incubation temperature (30 to 32 °C) are used, resulting in a comparably long fermentation period (about 10 hours) before the product has reached the required acidity of 70 to 75 °D. At that moment cooling starts, and the curd is broken up by careful and gentle stirring. As soon as the curd has reached a smooth consistency and is sufficiently cold, the yogurt is packaged in bottles, cups or other receptacles. Immediately after packaging the product is put in cold store for a further decrease in temperature. The moment the product has reached a temperature at which no further acid production takes place, it should have reached an acidity of about 90 °D. This means that the moment stirring and cooling starts should be chosen accordingly, and that the acidity of the product may be higher than the 70 °D mentioned before.

Long stirring unfavourably influences the consistency of the product. Therefore, it may be decided to stop stirring at the moment the product is smooth, but still warm. The product is packaged while still comparatively warm, and consequently depends to a large extent on cooling in the cold store. If the stirred yogurt is cooled by pumping it through specially designed coolers before it is packaged, temperature control is better, because in-package cooling takes much time, during which fermentation proceeds.

Both solid and stirred yogurt must be cooled to below 10 °C, preferably to below 7 °C.

Preservation of yogurt

The development of moulds and yeasts may be responsible for microbial spoilage of yogurt. The product can be preserved by:

- adding preservatives like sorbic or benzoic acid to the product,
- heat treatment of the product.

These processes also suppress the activity of the LAB and hence the acid production. The use of chemical preservatives is prohibited in many countries.

Pasteurization of yogurt, aiming to kill and destroy, or at least reduce, the microorganisms and the enzymes, affects its physical properties. The principal problem is associated with destabilization of the product by heat syneresis of the casein, i.e. whey expulsion. This can be overcome by pasteurizing the product at a pH below 4.4. A proper stabilizer must be added before heat treatment, unless the pH is lower than 4.0. Hydrocolloids, like gelatin, pectins, locust gum and starch derivatives may be used as stabilizing agents. They may be added during the preparation of the yogurt, either before or after fermentation. Since micro-organisms are more susceptible to heat in an acid medium, the intensity of pasteurization can be modest, e.g. 20 to 30 seconds at 65 to 70 °C.

Yogurt drinks have become quite popular. These are low-viscosity yogurts, to which sugar, aromatic compounds and other ingredients have been added. Homogenization at a pressure of about 100 atm gives the sour products (pH below 4.3) a drinkable consistency. Preservation by pasteurization is mild, e.g. 20 sec at 72 °C. Adding a stabilizer, e.g. 0.3-0.5% of pectin, will prevent destabilization caused by the proteins settling out during storage.

Flavoured yogurts

The addition of flavours, fruit juices and preserves to yogurt has become quite popular. Synthetic or natural juices and purees or mixtures can be used. Colouring agents, extra sugar or sweetening agents and stabilizers like pectins, gelatins and similar products may be added in quantities of a few tenths of a percent. Flavourings, sugars and colours can be added prior to fermentation. Fruit preserves or purees can be put in the packaging material before the yogurt is added. In this case the yogurt itself may already be flavoured. Another possibility is to mix fruit and other components with the stirred yogurt in bulk. In this case the fruit should be in small pieces and the stirred yogurt should be firm enough to prevent the fruit settling during packaging.

Concentrated yogurts

Milk for the production of yogurt is often boiled to improve the body of the final product. Sometimes, milk is heated for very long periods to concentrate the milk by evaporation of water, as in the production of Silivri yoğurt (Turkey). For this product, milk is brought to the boil over an open fire and than kept simmering over a low fire. After concentration, the milk is cooled to 45 °C and inoculated with a yogurt culture. The final thick product will have a layer of butterfat.

Diluted yogurts

Yogurt and yogurt-like products may be too viscous to serve as a beverage. The addition of water (up to 40 or even 50%) and thorough stirring or churning will provide a highly appreciated sour milk drink, like ayran in Turkey, doogh in Iran and a kind of lassi in India. Small quantities of salt and flavourings may be added to improve the taste. Sometimes, sugar is also added and products are obtained similar to sour milk shakes; for example, orange-flavoured yakkult in Korea.

Drained yogurts

The dilution of yogurt also reduces the acid taste. Some reduction can also be achieved by draining off some of the whey. The yogurt is packed in a clean cloth and hung up to drain. Drained yogurts, like labeneh in Jordan, still have a very high water content and are subject to spoilage. Products with a better keeping quality are manufactured by drying or heavily salting the yogurt.

Kiş yoğurt or winter yogurt in Turkey is preferably produced from goat's milk. The ripened yogurt is drained in cloth bags for about 6 hours and then simmered over a low fire for a couple of hours. At the moment simmering is complete, the product will have a solids content of about 30%. After about 2% salt has been added and the product has been cooled, it is packed in pots or jars and covered with vegetable oil to protect it from the oxygen of the air. The product is produced in the flush season to be consumed in the lean season. It must be stored in a cool place.

Simmering fresh (ewe's) milk until its volume is reduced by about one-third, using this concentrate for the production of yogurt, salting the fermented product and storing it in pots after the contents have been covered with vegetable oil is another method of preserving yogurt.

Industrially produced concentrated yogurt

Industrially produced concentrated yogurt, sometimes named 'Bulgarian yogurt', is manufactured from milk with a 50% increased solids content. Such a product can be obtained by evaporating some of the water under vacuum until the volume of the milk has been reduced to two-thirds, or by adding milk powder. The second method is simpler and less expensive. In both cases, special attention should be given to standardizing the fat content of the product to meet legal standards.

Milk for the production of Bulgarian yogurt is homogenized and pasteurized. If the solids content is increased by the addition of milk powder, the product must be homogenized and repasteurized after the powder has been completely dissolved. Homogenization preferably takes place at about 200 atm and a pasteurization temperature of 80 to 90 °C for a few minutes is used.

The concentrated product is inoculated with 4% of a yogurt culture and in-package incubated at 45 °C for about 2.5 hours. Immediately thereafter, the product is cooled as quickly as possible.

7.3.6 Other cultured milk products

A variety of other cultured products is produced, such as '*buttermilk with an increased fat content*'. This product is manufactured by culturing standardized milk that has a fat content of 2 to 3%. To improve the richness of the product, small granules of butter may be added. However, these granules will quickly rise and float on the surface. This may or may not be appreciated by the consumer. Flavours and colouring agents are added to produce *flavoured* and *coloured buttermilks*.

Cultured creams are produced by fermenting 10 and 20% creams with starters containing LAB and diacetyl-producing bacteria, as described in Section 11.1.

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8 Butter and ghee

8.1 Definition and description of butter

Butter is the fatty product exclusively derived from milk. Apart from milk fat it contains some non-fat milk solids, water and, occasionally, additives. Many countries apply the FAO/WHO standard for its composition (Table 12).

Several additives are permitted: sodium chloride (salt), cultures of lactic acid bacteria, certain harmless food colours and neutralizing salts. The difference between the minimum fat content on the one hand, and the non-fat milk solids content on the other hand allows for the addition of 2% additives, but more can be added, provided the water content is lowered. Since the solids-non-fat content is generally much lower than 2% and the salt content of butter – if salted at all – is usually below 1%, the fat content of the butter will necessarily be higher than 80%. Fat contents of 82 to 84% are no exception. Indigenously produced butter often does not meet official standards, and water contents of up to 30% may be found. Some countries have a standard for the fat content (80%) only; this renders the possibility of producing butter with a water content higher than 16%.

Contrary to milk and cream, where the fat globules are dispersed in the water phase, properly worked butter consists of a water in fat dispersion. The continuous phase consists of milk fat in which aqueous droplets, some fat globules and tiny air bubbles are dispersed. Butter is manufactured by churning sour milk or sour or sweet cream. This is accomplished by vigorously agitating the milk or cream in a vessel, thereby incorporating air and causing the fat globules to collect at the surface of the air bubbles which are dispersed in the liquid. The fat globules collide and coalesce, thus forming small clumps. The small clumps may collide and be pressed together to form larger clumps, which are visible with the naked eye (Figure 51). After the churning process

Table 12. FAO/WHO standard for the composition of butter.

Constituents	Percentage
Milk fat	minimum 80
Milk solids-non-fat	maximum 2
Water	maximum 16

Fig. 51. Stages in the formation of butter. Simplified and not to scale. Black is the aqueous phase; white is fat. Source: Mulder, H. & P. Walstra, 1974. The milk fat globule. CAB, England/Centre for Agricultural Publishing and Documentation, Wageningen, Netherlands.

is completed, the clumps are separated from the liquid, the buttermilk, and worked into either sweet- or sour-cream butter.

In practice, it is impossible to produce butter by churning sweet milk.

Further reading

FAO/WHO; Code of principles concerning milk and milk products, standard for butter and whey butter, no. A.1., Codex Alimentarius Comm., FAO/WHO.

See also 'Further reading' Section 8.3

8.2 Manufacture of butter

8.2.1 Traditional methods of butter making

In small-scale enterprises, such as farms, butter is generally produced from sour milk or cream that has not been heat-treated. Often, sour milk is churned, either because the quantity of milk is too small for the production of cream, or because the milk is of very poor quality and has curdled before any appreciable separation of cream by gravity could take place. Note that the churning of milk is unpractical: it requires large churns, much energy and produces much buttermilk; moreover, it leads to high fat losses – up to 25% – whereas when properly pre-treated cream is churned under controlled conditions, losses may be as low as a few per cent only. The purchase of a small hand-operated separator will prove to be economically justified in most cases where sufficient quantities of milk are available. Remember that the separation of cream by gravity is only practical for cow's milk (Section 5.3). If the quantities of cream produced daily are small, the cream of a number of days may be collected in a vessel, until sufficient is accumulated for churning. If neither milk nor cream is pasteurized, the spontaneous souring of cream is difficult to avoid, especially if cream is collected over a number of days.

Raw milk and cream can be contaminated with a wide variety of micro-organisms which give rise to various off-flavours. These flavours will taint the butter. Moreover, many of the contaminating micro-organisms may continue their activity in the butter, giving rise to serious defects like rancidity and the growth of moulds on the surface of the butter. Sometimes, consumers are used to a rancid flavour and do not find it objectionable. Occasionally, a putrid taste, which slightly resembles that of poor-quality cheese, may be noticeable. The addition of salt will prolong the keeping quality of butter and may mask the off-flavours to some extent.

It is very difficult to produce high-quality butter with a good keeping quality from non-pasteurized milk, but hygienic conditions of milking and milk and cream handling, including proper sanitization of all equipment, will contribute to the quality of the product. Furthermore, controlled souring of the milk or cream with a culture of lactic acid bacteria (Section 7.2), and consequently the production of sour-cream butter, will retard the development of undesirable micro-organisms. Usually, a very small amount of the previous day's sour milk or buttermilk is added (usually a quantity between 0.5 and 2.5%, depending on the quality of the inoculum, the temperature of incubation and the desired period of setting). At the moment of setting, that is at the moment the cream is ready for churning, it should have an acidity of about 70 to 100 °D, but in practice it will be found difficult to control the acidity sufficiently.

If the cream is separated by gravity, a considerable growth of all sorts of bacteria will have taken place before the cream is inoculated by lactic acid bacteria, and the quality may have been badly damaged.

If cream is to be collected over a number of days for butter making, the first batch should be inoculated. Every subsequent batch of cream added to the vat will thus be inoculated by the cream already in the vat. It is a good idea to stir each new batch of cream through the cream already in the vat. Since moulds and yeasts are able to grow in sour milk, churning should not be delayed for a long time after the milk or cream has reached the required acidity. If cream is collected from a number of days, the total period of collection should be as short as possible.

The sour skimmed milk and the buttermilk obtained as by-products of butter making are often used for direct consumption or for the production of sour milk products and cheese (Section 7.3, 9.2). Sometimes the quality of the buttermilk is so poor that it cannot be offered for human consumption.

If the production and handling of milk, cream and butter are exceptionally hygienic, it may be possible to manufacture sweet-cream butter, and sweet skimmed milk and buttermilk. The latter can be offered for consumption or processing. Sweet-cream butter is subject to a large number of defects, because the acid preservation is lacking. Salting improves the keeping quality of butter, especially of sweet-cream butter. Sour-cream butter is far safer for health reasons (Section 2.5).

The churning process can only be successful if part of the milk fat is already solid before churning starts, or if it will solidify rapidly during churning. For this reason the milk or cream should be sufficiently cooled and kept at a low temperature before churning (Section 2.2). In hot climates, proper cooling may prove to be difficult, especially if no artificial refrigeration or sufficiently cold water from the mains or a well can be made available. Under such conditions the milk or the cream must be put in

Fig. 52. Churning. Photo: J. J. Mol.

the coolest possible place. Generally, it will be possible to cool the milk overnight, when temperatures drop. In such cases, churning should take place in the morning before temperatures rise again.

The milk or cream to be churned must have undergone the best possible pretreatment. In stationary churns the foam production is brought about by vigorously rotating a stirring device or paddle alternately clockwise and anti-clockwise or by moving a plunger up and down in the liquid (Figure 52). These churns can be made from almost any material and be of various shapes: earthenware pots, wooden or metal vats, a cylinder of hollowed-out bamboo, etc. Other churns are brought into motion by rotating them or moving them to and fro, so that the liquid is agitated vigorously. These churns may be as simple as bags made from animal skin, or wooden barrels, but modern dairy equipment may also be used.

After a certain period of churning, usually about 30 minutes, butter granules will have formed, and granules and buttermilk can be separated by hand or with the aid of a sieve. Thereafter, the granules are usually washed with potable water. This can be accomplished by shaking the granules with the water in the churn or in another receptacle. After washing, the granules are separated from the washing water and kneaded to a lump, meanwhile squeezing out the excess water. Kneading is continued until all 'free water' and 'free air' are removed. The remaining water and air must be evenly distributed through the butter lump in such a way that droplets and air bubbles are no longer visible. Kneading may be done by hand or with a spatula, but special butter-workers also exist. During kneading, salt may be added to the butter.

If the daily production of butter is small, one day's output may be lumped with the previous day's production and kept floating in brine or in buttermilk, which must be renewed every day. The butter can also be stored in a pot or other container.

Butter produced by traditional methods has a very limited keeping quality, especially if it is not stored under refrigeration, and should be consumed as quickly as possible after manufacture. If the butter is stored over longer periods, it will become rancid and mouldy and a very unpleasant flavour will develop.

Further reading

See Section 8.3

8.2.2 Industrial manufacture of butter

Washing of cream

Cream for butter making may be washed if it is obtained from poor-quality milk, to remove off-flavours in the plasma. The cream is diluted with warm potable water to a fat content of about 10%. After being mixed thoroughly, the diluted cream, which should preferably have a temperature of about 40 °C, is separated again into a watery liquid and washed cream. The content of non-fat milk solids and off-flavours in the latter is only about 20 to 30%. A still larger reduction may be obtained by repeated washing. The system of washing is not often practised because it is labour-intensive and time-consuming, and gives rise to heavier fat losses; moreover, defects in the lipid fraction will not be reduced.

Pasteurization and deodorization

The objectives of pasteurization in butter manufacture are:
- destruction of micro-organisms,
- inactivation of enzyme activity,
- production of active sulphydryl compounds (SHC) (Section 6.5).

Two systems of pasteurization are used:
- whole-milk pasteurization,
- separate cream and skimmed-milk pasteurization, or, in the event of direct standardization, separate cream and standardized-milk pasteurization.

Separate pasteurization has the advantage that the separator cannot recontaminate the pasteurized milk. Moreover, the skimmed milk or standardized milk and the cream can undergo different heat treatments, e.g. the former a moderate treatment as required for pasteurized milk or cheese milk, and the latter an intensive treatment as required for butter making.

In the whole-milk process, the milk is separated after heat treatment. If the milk is pasteurized at a low temperature, the cream may be repasteurized at a much higher temperature.

If only small quantities of cream are available, it may be difficult to pasteurize the cream immediately after separation in continuous flow. Under these circumstances, the best strategy is to collect the cream until a sufficient quantity is available for pasteurization. For reasons of quality it is not advisable to store the cream at elevated temperatures, for instance at separation temperature, especially if the cream is still raw. Intermediate cooling is advisable, although lipolysis may be difficult to avoid (Section 2.2).

Batch as well as flash pasteurization of cream is possible. The former is a satisfactory method if only small quantities of cream are available. Otherwise, pasteurization and cooling of cream in continuous flow is to be preferred. Flash pasteurizers can be connected to a vacuum deodorizer to remove some objectionable odours and flavours.

Intensive deodorization is achieved with systems of direct heating, by injecting steam and then cooling under reduced pressure. The steam condenses and transfers its heat to the cream, thus diluting and pasteurizing it. In a chamber with reduced pressure, an amount of water equal to the quantity of condensed steam evaporates. The released water vapour is carried off together with some if not all of the volatile gases and objectional flavours in the cream. This system of pasteurization is very similar to the direct heat treatment of milk (Section 6.2).

Cooling and fermentation

Immediately after pasteurization, the cream is cooled to the ripening temperature, either in batch, or in tubular or plate heat exchangers (coolers). Surface coolers can be used, especially in small-scale operations. While the cream passes over the open cooler, some deaeration takes place and some objectionable flavours disappear. Since it takes a long time to cool cream in batch, batch pasteurization may be followed by cooling in a tubular or plate heat exchanger or over an open cooler.

After cooling, the cream is pumped into the ripening vats or tanks, which usually either consist of horizontal half-cylindrical vats or vertical cylindrical vats, both types double-jacketed and provided with stirring devices. Liquids for cooling and warming the cream can be circulated through the jackets and sometimes through the stirring devices, in which case the latter consist of a piping system.

Ripening the cream for butter making has two objectives:

- to ferment (acidify) the cream with a starter if sour-cream butter is made,
- to solidify part of the butterfat, to make the cream fit for churning, in such a way that the churning process (i.e. the time needed for churning) and the fat losses in the buttermilk can be controlled.

The temperatures for ripening and also for churning largely depend on the melting range of the milk fat. This means that under similar conditions, the temperatures will be higher for buffalo's milk than for cow's milk (Section 2.2). The temperature treatment of the cream also depends on the required consistency of the butter (Section 8.3). Temperatures may vary from 12 to 18 °C. Under tropical conditions, the temperature may usually be kept between 13 and 15 °C, and so may the churning temperature. High churning temperatures may be responsible for high fat losses, but a short churning process. The amount of starter is adjusted to the ripening temperature and may vary from about 2% of the cream for the higher temperatures (e.g. 18 °C) to as much as 8% for the lower temperatures (e.g. 13-15 °C). The activity of starters may be found to be too low at very low temperatures, for instance at temperatures below 13 °C, to achieve a satisfactory souring of the cream.

Since the time available for fermentation depends on the working programme of the plant, the cream may have to be cooled immediately after it has reached a certain acidity, in order to stop or to limit further acid production. The final acidity of the cream will vary between 65 and 80 °D, depending on its fat content. A more reliable standard is the acidity of the filtrate obtained by pouring the cream over a paper filter. The acidity of the filtrate should be about 45 to 50 °D.

Churning the milk or cream and working the butter

Butter making is actually a two-step process:
- concentrating the fat globules to fat granules and separating the granules from the other constituents of the milk or cream, namely the buttermilk;
- working or kneading the granules to obtain a homogeneous fatty product, the butter, by which the fat in water dispersion is reversed into a water in fat dispersion.

Churning

During churning, milk or cream is – as has already been explained – subjected to an intensive agitation, characterized by copious foaming, in a churn. Modern industrial churns are mostly made of stainless steel and are cylindrical, cubic or conical (Figure 53). They can rotate at various speeds, depending on the process conditions. Churns are equipped with a manhole that can be closed with a lid and one or more valves. At the beginning of the churning process and during washing of the butter granules, high speeds are usually used, whereas at the end of the churning process and during kneading of the butter, speeds are much lower.

The churn is usually filled to 40 to 50% of its capacity. Shortly after churning has started, the remainder of the churn becomes filled with foam, consisting of air bubbles to which the fat globules will adhere. Part of the membranes and the liquid fat of these globules spread over the surface of the air bubbles. As the churning process continues, the bubbles collide, combine and burst, thus decreasing their total surface. During this process, the fat globules congregate at the smaller surface where they will coalesce to form granules, the liquid fat acting as a sticking agent. Part of the liquid fat will escape granule formation and will be distributed in the buttermilk in the form of minute droplets, often named colloidal fat. The small granules collide and unite, gradually becoming larger, until they are visible to the naked eye. At this moment, the liquidizing

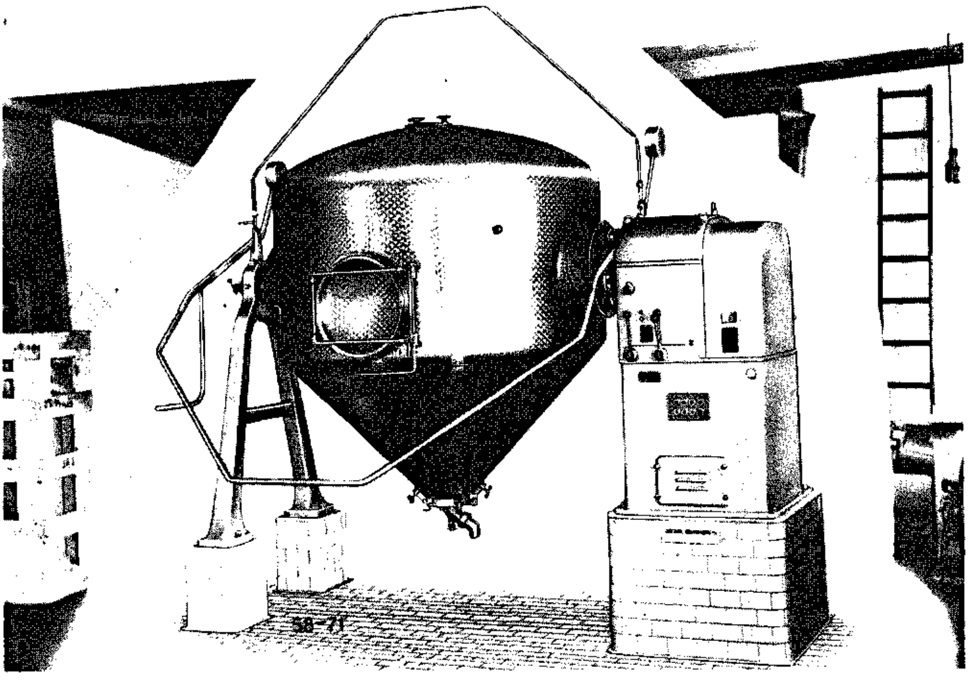

Fig. 53. Metal churn. Courtesy: Pasilac AS.

moment (that is the moment foaming diminishes), the speed at which the churn rotates is decreased, to allow the granules to grow still more. Simultaneously, the liquidity of the contents of the churn seems to increase.

As mentioned already, the production of butter is practically impossible if none, or only a very small part of the fat is solid during churning. A minimum quantity of the fat must be solid at the moment churning starts. On the other hand, the larger the quantity of solid fat, the slower the churning process will proceed, but the lower the fat losses in the buttermilk will be. If, during churning, it is found that too much fat is solid, lukewarm water of potable quality can be added to speed up the churning process. On the other hand, cold water can be added to cool the contents of the churn and to solidify more fat.

The churning process will take about 30 to 45 minutes under normal conditions. At the end, the butter granules will have a diameter of about 3 to 5 mm. If the churning process is continued at low speed, the granules will continue to enlarge. Very small granules will hinder a complete separation of granules and buttermilk, whereas very large granules may include too much buttermilk, which may prove difficult to remove by the kneading process.

During the first few rotations of churning, pressure will build up in the churn as a result of the liberation of carbon dioxide, dissolved in the cream. The excess pressure must be released by stopping the churn and by opening the valve of the churn that is in its highest position.

Many factors influence the churning process, such as:
- the state of crystallization of the milk fat,
- the acidity of the cream,
- the fullness of the churn,
- the fat content of the cream.

The combined influence of these factors is very complicated, not least because several objectives are to be achieved, such as an excellent taste, flavour and consistency of the butter and a low fat content in the buttermilk. The correct procedure of butter making must be found by experience; detailed information about the major factors influencing this procedure can be found in specialized manuals or textbooks.

Washing the butter granules

Churning is stopped at the moment the butter granules have obtained the desired size, and the buttermilk is then drained off. Some of the coagulated protein particles will remain on the granules, because the latter act as a sieve, especially if they are small.

The addition of some water before draining will promote a better and more complete separation of granules and buttermilk. A first quantity of water may be added at the moment the cream liquidizes, a second quantity at the moment churning is finalized. The second addition (10% of the original contents of the churn will be sufficient) is especially important; it should be sprayed over the butter granules that are floating on the buttermilk. In this way, the water will form a layer on top of the buttermilk, with the granules floating on the water. This will facilitate separation of granules and buttermilk. Not too much water should be added, especially if the buttermilk is destined for consumption.

After the buttermilk has been drained off, water can be added so that any remaining buttermilk will be washed off the granules. Moreover, the firmness of the granules can be adjusted with the temperature of the water. They are generally cooled with the water, which must be of potable quality. Water that is contaminated with bacteria may be chlorinated before use, but care must be taken not to impart an objectionable flavour to the butter. If the buttermilk is of poor quality, it is particularly important to ensure that the butter granules are washed properly. The efficacy of washing should not be overestimated, because the buttermilk included in the butter granules will not be affected. Butter produced without washing will have a higher solids-non-fat content, which means a higher yield. The usual procedure of washing is to add a quantity of wash water to the contents (the quantity equals the quantity of drained buttermilk), rotate the churn several times and then drain off the water again. If necessary, washing is repeated.

The first wash water has a high protein content. After it has been allowed to settle and the overlying liquid has been removed, this protein concentrate can be used for animal feed.

Working the butter

After the buttermilk or wash water has been drained off, the butter granules are ready for working, that is kneading. The objectives of working are:

– to bring the separate granules together to form a homogeneous mass,

– to remove buttermilk and water in order to achieve the desired water content of the butter,

– to distribute the moisture in the butter in the form of the smallest possible droplets.

Churns may be equipped with a separate kneading device, but most modern churns are equipped with special boards which carry the mass of butter upwards during rotation until the churn has reached a position from where the butter drops downwards. The pressure exerted on the butter as a result of the smash at the moment it hits the lowest point of the churn is sufficient for an efficient kneading procedure. During kneading the granules are pressed together and part of the watery phase will be pressed out so that it can be drained through the valves of the churn until the mass of butter has the desired water content. At that moment the valves are closed and kneading is continued until the remaining water is evenly distributed in the butter in the form of

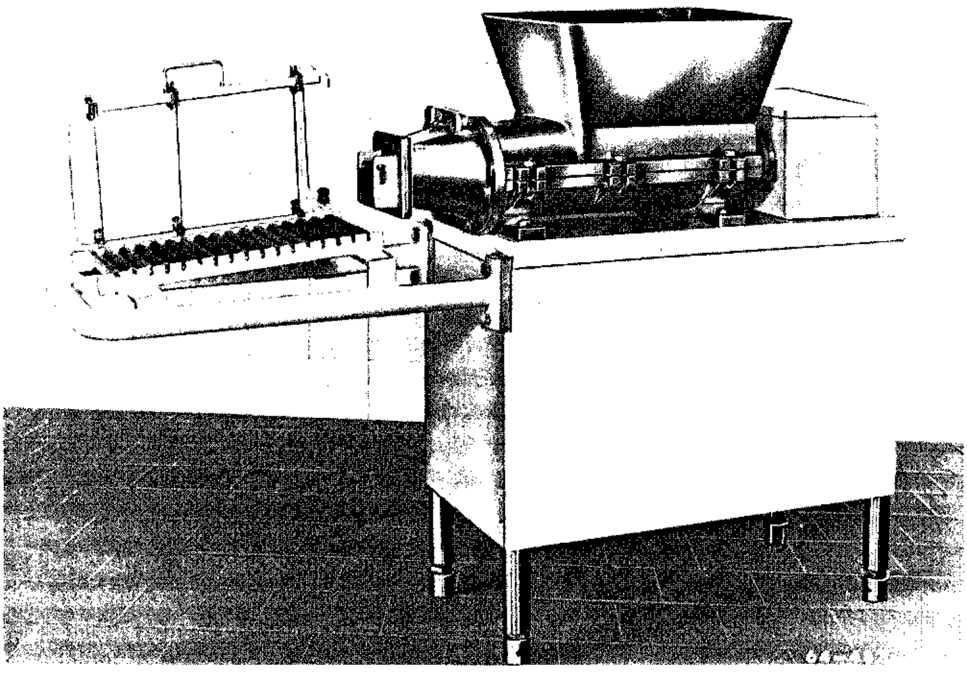

Fig. 54. Hand-operated butter printer. Two counterwise revolving veriform axes in the container press a long block of butter through a square opening over the roller track. By bringing down the adjoining frame, which has metal wires at equal distances apart, the block of butter is cut in pieces of equal weight, which can be packed by hand. Courtesy: Pasilac AS.

minute droplets, invisible to the naked eye. If the water content of the butter proves to be too low, some water can be added to the butter and this water can be distributed through the mass by kneading with the valves closed. The speed of rotation during kneading is much lower than during churning, especially if the aim is to remove water. For an even water distribution (small droplets) and to incorporate added water, the speed should not be too low.

Salt and other additives like colouring agents may be added during the kneading.

Butter must have a certain firmness during kneading, otherwise it will not be possible to remove – or incorporate – water and to obtain 'dry' butter, that is butter with the required fine distribution of moisture. The presence of visible water droplets does not necessarily give an indication of the water content of the butter. Perfectly dry butter may have a high water content (e.g. 30%), whilst the water content of 'wet' butter may be well below the legal standard.

Butter may be packed in crates, cartons or other containers lined with parchment-paper. Butter for retail sale is packed in tins or in cups, usually of plastic, or formed into convenient shapes and wrapped in parchment-paper, aluminium foil or plastic (Figure 54).

Processing sour cream

Some dairy plants receive cream instead of milk. Usually it is received in cans as a thick sour substance, which adheres to the walls of the cans when they are being emptied. The adhering cream can easily be collected by inverting the cans on a rack over an open vat and by spraying a jet of steam into the cans. The combined action of heat and condensed steam will dislodge the cream.

Sour cream may also be produced at the plant, if milk with an increased acidity is separated (Section 5.1). Cream with an increased acidity cannot be pasteurized, because the coagulated casein will block the pasteurizer. Therefore, the acidity of such cream must be brought back to normal by the addition of neutralizing salts, usually sodium bicarbonate, which must be absolutely pure.

The quantity of salts to be added to the cream depends on the acidity and the fat content of the cream, because all the acid is concentrated in the plasma. The plasma acidity of cream with an acidity of A °D and a fat content of F % is (in °D):

$$\frac{100\,A}{100 - F}$$

To reduce the acidity of 100 kg of cream containing F % of fat by 1 °D requires 1.06 $(100 - F)$ g of sodium bicarbonate.

Neutralized cream usually has an off-flavour, and deodorization is advisable. Some of the flavours can be removed by washing the neutralized cream. After neutralization, pasteurization and deodorization or washing, the cream can be used for the production of sweet-cream butter, or, after fermentation, for sour-cream butter.

Further reading

See Section 8.3

8.2.3 Continuous butter making

Butter making as described in the previous paragraphs is a discontinuous process in which cream is churned in batches. Methods and equipment for continuous manufacture have also been developed, but considerable quantities of milk fat must be available to justify the introduction of continuous production on technical and economic grounds. Such conditions seldom exist in countries with a developing dairy industry; especially not if the availability of milk fat depends exclusively on the surplus fat that will be obtained as a result of the standardization of milk.

Of the various procedures for continuous butter making, only the system that uses an accelerated churning procedure will be briefly discussed.

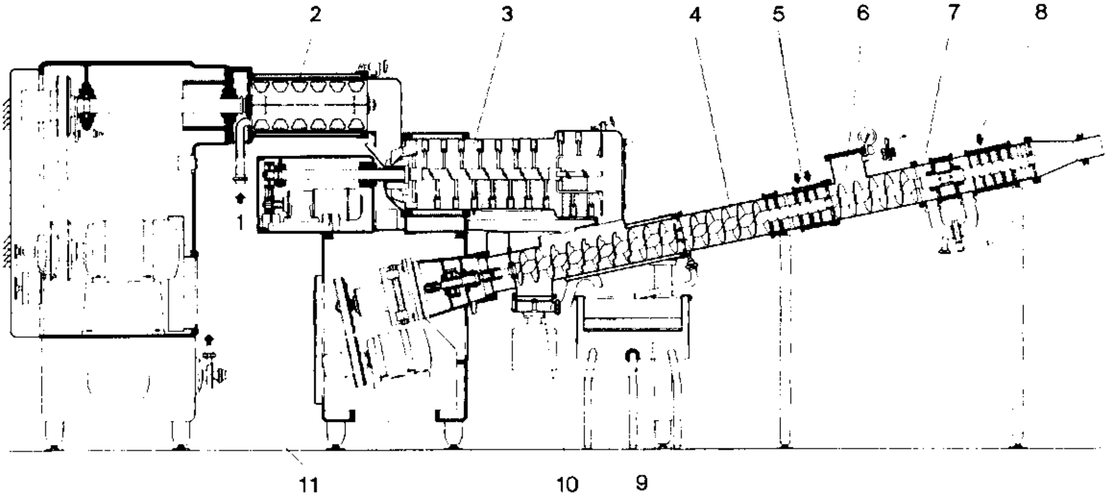

Fig. 55. Continuous butter-making machine. The cream to be processed is conveyed (1) to the primary churning cylinder (2), where it is partly separated into butter granules and buttermilk, which flow into the secondary churning cylinder (3). After completion of the churning procedure, buttermilk and granules flow into the texturizer with augers. The buttermilk is collected in the *buttermilk-clarifying device* (10), where the small butter granules carried along with the buttermilk are collected and agglomerated. They are fed back to the texturizer. The clarified buttermilk flows into the buttermilk vat (9), from where it is pumped (11) away. The augers convey the butter granules to the first blending section (4), where additives such as water, cultures and salt can be added and mixed into the product (5). Air is evacuated from the butter in the vacuum chamber (6). Augers and a butter pump convey the butter to the second blending section (7), where water can be added (8) to the butter for standardization of the water content. Intensive mixing in this section ensures a homogeneous texture and a fine moisture distribution. Courtesy: Westfalia Separator AG.

Pasteurized cream with a fat content up to 45-50% is ripened sufficiently long to solidify part of the fat and to attain the desired acidity if sour-cream butter is to be manufactured. After ripening, the cream passes through one or two double-jacketed cylinders, where high-speed rotating vanes churn the cream into butter in a few seconds. The cylinder is cooled by circulating water through the double jacket. Buttermilk and butter granules drop into another – inclined – cylinder, in which two worms rotate in opposite directions. In this cylinder the buttermilk flows off and the butter granules are kneaded into butter on their way through the cylinder (Figure 55).

8.2.4 Direct souring of butter

Most consumers prefer sour-cream butter to sweet-cream butter, but it is sometimes found difficult to market large quantities of sour buttermilk. Since sweet-cream buttermilk can be put to several uses in a dairy plant, a compromise between the consumer's preference for sour-cream butter and the uses of sweet-cream buttermilk is to produce sweet-cream butter through which a natural or artificial butter-aroma extract is kneaded. A starter containing lactic acid and aroma bacteria may be kneaded through the butter as well, although the development of such bacteria in dry butter that contains tiny water-droplets only, will be poor or even negligible.

8.2.5 Fat losses and butter yield

Two steps in the buttermaking process are responsible for fat losses:
- the separation of milk into skimmed milk and cream, with fat losses in the skimmed milk;
- the churning of cream (or milk) with fat losses in the buttermilk.

Buttermilk may have a high fat content for a number of reasons, such as:
- sweet cream is churned instead of sour cream;
- low-fat cream (or milk) is churned;
- cream with too little crystallized fat is churned;
- the churn is not sufficiently filled;
- very high rotational speeds of the churn are practised.

Fat losses in butter making should not exceed 2% of the fat available in the cream.

Under normal conditions, 100 kg of cream with a fat content of F % will give a butter yield (in kg) of:

$$F \times \frac{98}{100} \times \frac{100}{84}$$

In this formula, 98 stands for the percentage of milk fat that is transferred from the cream into the butter, whereas 84 stands for the fat content of the butter.

8.3 Quality of butter

Consistency

Butter consists of a continuous phase of liquid fat in which fat crystals, fat globules, ruptured fat-globule membranes and moisture droplets are embedded. Butter also includes some small air bubbles. The free butterfat is formed during churning and kneading. The total quantity varies with the composition of the fat, the processing technique, etc., but up to 50% of the fat is still present in the form of globules.

The fat globules and the crystallized fat in the butter together form a structure that determines the consistency of the butter. The amount of crystallized fat depends on the composition of the fat and the temperature. The most important features of the consistency are the firmness and the spreadability.

Since dairy plants can exercise little or no influence on the composition of the milk fat, they must control the consistency, in this case the firmness, of the butter by treating the cream appropriately after pasteurization, during ripening, churning and washing. Moreover, the mechanical treatment of the butter during working and printing (packaging) as well as during storage play an important part. Differences achieved in the processing technique are of limited value under tropical conditions, because these differences are particularly significant at temperatures between 12 and 18 °C. These temperatures rarely prevail under tropical conditions, where butter is either subject to ambient temperatures above 20 °C, or where the butter is kept in refrigeration at temperatures well below 10 °C. For this reason, differences in processing techniques that control the consistency of butter at moderate temperatures will not be discussed.

Butter will harden considerably if it is put in cold store after manufacture, especially if much free fat is available for building up a solid butter structure. If such butter is kneaded several days after it is put in cold store, the structure will be destroyed and the butter will show a much better spreadability; even printing butter will improve the spreadability. Although such butter will harden again, the final firmness will be lower and the spreadability will be better than originally. Nevertheless, butter taken from the refrigerator will be found to be hard and difficult to spread. The spreadability can be improved by carefully warming up the butter, but if this is overdone; the butter will melt or 'leak out'.

Butter should have a homogeneous structure and uniform colour. The surface of old cow's-milk butter may have a deep yellow colour, as a result of drying out. Sometimes, butter is coloured by the addition of colouring agents like annato or carotene. More intensive colours – in some countries an orange colour is preferred – can be obtained by the use of synthetic pigments. The colouring agents should not be harmful to health. In many countries only the addition of carotene is permitted.

Flavour

High-quality sour-cream butter must have a pleasant fresh aromatic flavour, with a suggestion of acidity. Diacetyl is the major aroma compound (Section 7.2), produced by aroma bacteria present in the starter. Starters that fail to produce the required aroma, or even produce off-flavours, must be replaced. Sweet-cream butter has a different aroma, which may be described as slightly nutty, whilst the taste of the milk fat is much more dominant than in sour-cream butter.

A poor or defective taste or flavour of fresh butter is usually the result of the poor quality of the milk or the cream. Certain defects can develop during storage. The principal defect is rancidity, due to lypolysis of the milk fat caused by lipolytic enzymes originating from the milk or produced by micro-organisms developing in the butter. Butter with a poor moisture distribution is especially liable to develop a rancid flavour. Contrary to tiny moisture droplets, large droplets will give rise to the development of micro-organisms, which produce lipolytic enzymes responsible for the rancid flavour. Moulds may develop on the surface of the butter, where they produce enzymes responsible for a rancid flavour. If butter contains a network of large air bubbles (porous butter), moulds may also develop in the butter, causing marbled butter, which is not only a defect as such, but which also enables a rancid flavour to form quickly throughout the butter.

Butter can sometimes be described as unclean or cheesy. These defects are caused by the activity of proteolytic bacteria, often psychrotrophic ones.

The storage life of butter can be prolonged considerably by keeping the butter in cold store at temperatures below freezing point, preferably below −20 °C. At these temperatures, no bacteriological defects will develop, but butter may develop chemical defects as a result of fat oxidation. Butter with these defects is described as tallowy, fatty or fishy. The oxidative process is typical for sour-cream butter, especially if it is salted. It is highly catalysed by copper contamination. Sweet-cream butter, even if it is salted, is far less affected by this defect. Anti-oxidants added to butter may retard the occurrence of the defect, but such additives are prohibited in most countries. Intensive heat treatment of the cream is recommended, to protect the butter against oxidation. Free sulphydryl groups are liberated from certain sulphur-containing amino acids. These groups act as 'natural anti-oxidants'.

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8.4 Definition and description of ghee

Because of the fairly high water content, the keeping quality of butter is poor, especially if the product is produced from raw milk or cream under unhygienic conditions and when no facilities for refrigeration are available. The disadvantage of the high moisture content can be circumvented by the production of ghee. This is a product produced by heating cream or butter with the objective of removing as much of the moisture as possible. Heating will destroy most of the micro-organisms and enzymes. The low moisture content will hamper the development of organisms that survived heat treatment or that recontaminated the product.

Most ghee is produced from buffalo's or cow's milk. Ghee can be defined as 'a product exclusively obtained from milk, cream or butter from various animal species, by means of processes, which result in almost the total removal of moisture and solids-non-fat contents, with an especially developed physical structure' (IDF definition). The taste should be nutty with a slightly cooked or caramelized flavour, but there are considerable regional differences. Some consumers prefer a more pure, bland flavour, whereas others like a much stronger flavour and do not object to a rancid taste.

The product should consist of large milk fat crystals, floating in liquid fat, giving the product a coarse appearance. The colour of ghee depends on the type of milk and the production method. Ghee from cow's milk has a yellowish-orange colour, whereas ghee from buffalo's milk has a whitish, pale cream colour with a greenish tinge.

Further reading

See Section 8.6

8.5 Manufacture of ghee

There are three methods for the production of ghee:
- the indigenous milk-butter process,
- the cream-butter process,
- the direct cream process.

8.5.1 Indigenous milk-butter process

On traditional farms, butter is directly produced from milk (desi method). Sour milk may be churned every day, but if the daily milk production is very low, milk from a few days may be collected. The moment a sufficient quantity of butter has been produced, or collected over a number of days, it is melted in an open pan over an open fire to evaporate the water (Figure 56). At first, the temperature of the melted butter will be between 100 and 105 °C. It will froth, and scum and sediment will be formed. The scum consists mainly of proteins and impurities, the sediment of milk solids-non-

Fig. 56. Ghee making. Courtesy: Royal Netherlands Dairy Federation.

fat. When practically all the water has been evaporated, frothing will stop. The water content will be about 1%. From that moment on, the temperature of the melted fat will rise to about 115 to 120 °C and the sediment in the melted butter will gradually darken. The sediment will produce fine bubbles that rise to the surface and a pleasant, typical aroma will become perceptible. When the colour becomes brown, heating is stopped and the ghee is filtered through muslin and packed in pottery, metal or glass containers.

8.5.2 Cream-butter process

This is a three-step process of ghee production which is applicable under small-scale farm conditions as well as under large-scale industrial conditions. Cream is separated from milk and churned into butter, or only into butter granules. Then the butter is converted into ghee. Cream for butter making, or butter, may be collected over a number of days. Farm-made butter is not necessarily converted into ghee on the farm. It is often collected by merchants, and ghee production is centralized.

If large quantities of butter are available it is worthwhile using the 'clarified-butter method', also known as the 'induced-stratification method' or the 'stratification method'. Butter is melted in a steam-jacketed vat to a temperature below boiling point, such as 85 °C, for about 30 minutes. The butter melts and destabilizes. Then the product is allowed to settle undisturbed and three layers form: a top layer of denaturated proteins and impurities, a middle layer of almost pure butterfat and a lower layer of 'buttermilk'. The lower layer can be drained off, the top layer can be skimmed, thus leaving a ghee with a rather bland taste and a relatively high water content. Because of this high water content, the ghee will deteriorate rapidly.

To obtain a product with a stronger flavour and an improved keeping quality, the decanted butter oil is reheated with the scum to a temperature of 110 to 120 °C to lower the moisture content still further. The proteins in the scum will suffice for the development of more flavour. However, the resulting ghee will still not have such a pronounced flavour as ghee made by the process in which the water is completely removed by evaporation only, that is without draining off the buttermilk. Increasing the temperature to 130 °C and higher will result in a 'heated flavour' and the development of a dark colour.

The water content of the ghee after stratification is too low for the development of micro-organisms. Therefore, the rapid deterioration of ghee cannot be explained by the development of such organisms; however, the water content may be sufficiently high for the activity of lipolytic enzymes. Another possibility might be that the deterioration does not result from hydrolysis of the fat, but from its oxidation. In this case the improvement of the keeping quality achieved by reheating the ghee to 110 to 120 °C could be explained by the formation of reducing compounds from the proteins still left in the product. These compounds could retard fat oxidation.

8.5.3 Direct cream process

This process omits the production of butter, because cream is converted directly into ghee. It is especially suitable for large-scale production, using fresh cream, cultured cream or washed cream (although the washing of cream is of far less importance than in the other methods, if the stratification method is applied). Ghee is produced from the cream in a two-step process. In the first step the cream is heated in a steam-jacketed kettle for a few hours. During this period the cream boils vigorously and froths, and most of the water evaporates. The temperature remains below 105 °C. In the second step the temperature starts increasing, the frothing ceases and the solids-non-fat darken. At this point, almost all water has evaporated. To prevent overheating, the steam supply to the jacket must be reduced to keep the temperature below about 115 °C. The moment the colour of the residue has changed from creamish to brown, the process of heating must be stopped and the ghee must be filtered through a muslin cloth. After filtering it is packaged and cooled.

Since the melted butter fat still contains all the solids-non-fat during heating, the final product will have a rather pronounced flavour. A less pronounced, bland flavour will be obtained if the cream is washed before heating. About 1% of the fat will be lost with the filtering.

A less intense flavour and a lower loss of fat can be realized by practising the stratification method at the moment the cream is sufficiently heated, so that the fat becomes completely destabilized. Stratification also allows for a milder flavour.

8.5.4 Butterfat losses

Under primitive conditions of manufacture, fat losses are very high if the milk-butter process is practised. Sometimes, less than two-thirds of the fat in the milk is recovered.

Fat losses in the cream-butter process and the direct-cream process are much lower, say about 15 to 10%, but published data vary widely and often seem unreliable.

The stratification procedure lowers the fat losses.

Further reading

See Section 8.6

8.6 Quality of ghee

There is wide variation in the appreciation of the various qualities of ghee. Consumers may prefer a rather milky aroma, or a strong, intense aroma. Smoky and rancid flavours may be rejected or appreciated. Very light or rather dark colours may be preferred. But in general, there is little difference of opinion in respect of the consistency of ghee; it should have the appearance of large crystals floating in liquid fat.

The description of the methods of manufacture give an indication of the manufacturing process that must be followed to obtain a product of the desired quality.

Colour

Ghee produced by the direct cream method has a darker colour than that prepared by the cream-butter process, whereas cultured milk or cream will give a darker colour than sweet fresh milk or cream. Stratification will be responsible for a light colour. A more intensive heat treatment after most of the moisture has been evaporated, in the presence of a higher solids-non-fat content will result in a darker colour, especially if the raw material has been fermented.

The influence of the process of manufacture will be more marked in the case of buffalo's milk, which is whitish, than in the case of cow's milk, which is yellowish, because to a certain extent the yellow colour masks differences resulting from manufacture.

Flavour

Tastes and odours are difficult to describe, but ghee should have a pleasant, slightly nutty and cooked or caramelized flavour. In general, the flavour will be more pronounced if the heat treatment was more intensive, the solids-non-fat were still present during heating and the product was produced from cultured milk or cream. Some believe that the kind of fermenting culture influences the flavour. Heating the ghee will give the product an intense flavour and colour, especially if the temperature rises above 130 °C.

The quality of the raw material, that is the milk or the cream, has a distinct influence on the flavour of the fresh ghee. Defects confined to the serum can be alleviated by washing the cream and/or using the stratification method. Defects of the milk fat will be found in the ghee. The most important fat defect is the result of lypolysis liberating fatty acids and thus giving the product a rancid flavour.

Ghee produced by traditional methods on open fires may have a smoky flavour.

Consistency

If butterfat is cooled rapidly, a large number of very fine crystals will be formed simultaneously, all consisting of mixtures of fats with high and low melting points. The small crystals form a structure that includes the liquid fat, thus giving the product a smooth character.

If butterfat is cooled slowly from a temperature higher than the 'melting point', a few crystals consisting of fats with a high melting point will be formed in the beginning. As cooling proceeds, more and more fat will solidify, but it will form hardly any new crystals, if at all. Most of the solidifying fat will precipitate on the existing crystals, which will grow slowly, forming a mass of large crystals suspended in a quantity of liquid fat, which has a melting range too low to solidify.

The consistency of the ghee will not only depend on how the ghee is cooled after production, but also on the glyceride composition of the fat. Moreover, the storage conditions of the ghee are important. If the storage temperature rises, fat will melt. During subsequent cooling, this fat will solidify again. Since solidification will be slow, the original structure of the ghee is likely to be maintained.

Keeping quality

Ghee may deteriorate because undesirable flavours develop as a result of chemical reactions or biological activities, giving rise to two major defects: oxidized flavour and rancidity, respectively.

Oxidized flavour. The oxidation of the milk fat will cause a bland flavour initially, but later, unpleasant oxidative defects, such as tallowiness will develop. At the same time, the natural colour of the product may fade. Butterfat is susceptible to oxidative deterioration resulting from the presence of air (oxygen). Oxidation is catalysed by exposure to light and the presence of copper. To extend storage life it is important to package ghee in light-excluding materials and to fill the package completely, avoiding any inclusion of air. Contamination with copper and, of less importance, iron, must be avoided.

In many cases, the milk has already been contaminated at the farm by the use of brass or copper milking utensils. Some of this copper accumulates in the protein and in the fat-globule membrane, but significant amounts may remain in the ghee after the buttermilk and the solids-non-fat have been removed. All utensils and processing equipment used in the milk plant should be manufactured from stainless steel, aluminium, or properly tinned copper or brass. Brass or copper pots are unfit for the storage of ghee; iron, glass, porcelain, etc. are to be preferred. If glass is used, the pots should be stored in a dark place to protect the ghee against light.

Low acidity of the fat and the presence of natural anti-oxidants are believed to extend storage life. Cow ghee is more stable than buffalo ghee because it contains more natural anti-oxidants. During heating, especially after most of the moisture has been evaporated, the production of anti-oxidants from phospholipids is induced. It is believed that these heat-modified phospholipids are absorbed by the fat and thus contribute to the keeping quality of the ghee. It is the higher content of these anti-oxidants that is thought to be responsible for the improved storage life of unfiltered ghee. Ghee produced by the direct cream method is more stable than ghee produced by the cream-butter method, because of the longer heat treatment and the higher phospholipid content.

Cool storage, e.g. at 15-20 °C, retards oxidative changes, but cold storage may cause a greasy consistency.

Rancid flavour. The intensive heat treatment involved in manufacturing ghee should destroy most bacteria, and only a few bacterial spores should be present. As a matter of fact, certain *Bacillus* species (*subtilus* and *megatherium*) are found in ghee, but in addition to these microbes, ghees may be severly contaminated with lactic acid bacteria, moulds and yeasts, in numbers that largely depend on the hygiene prevailing when the ghee was handled and packaged.

Rancidity in ghee may develop as a result of the activity of lipase produced by micro-organisms that are able to grow in ghee provided it contains sufficient moisture. The dispersion of the moisture in the product is also important. Large droplets are more conducive to micro-organisms than small droplets (Section 8.3).

Buffalo ghee is believed to be more resistant to lipolysis, or – at least – to the development of rancidity than cow ghee.

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8.7 Anhydrous milk fat

Anhydrous milk fat or butterfat is a kind of ghee without its essential flavour or aroma. It contains hardly any components other than pure fat, which has not undergone any appreciable microbiological or chemical changes. The highest grade (highest quality) is especially suitable for the production of recombined milk and milk products. But even the slightest defects in the product make it unsuitable for this purpose. Therefore, it should be produced from high-quality fresh milk or cream, rather than from butter, not even sweet-cream butter if it is not absolutely fresh, let alone low-grade butter or sour-cream butter. The content of water and free fatty acids, and the peroxide value (a measure of fat oxidation) must be very low, to guarantee a long keeping quality.

Although its original quality may be excellent – especially if the containers in which the product is packaged are flushed out with nitrogen during filling – the keeping quality is easily overestimated if storage temperatures are high. Even premium-grade anhydrous milk fat may spoil within three months if it is stored at temperatures of 30 °C or higher. Therefore, it is recommended to keep small stocks in a cool place.

Somewhat lower grades of milk fat or butterfat, which do not meet the international standards for anhydrous fat, are excellent for other uses, such as for cooking, in some food industries, etc.

Only well-equipped dairy plants are able to produce pure milk fat of the 'anhydrous standard'. Several production methods are practised; they are classified in two basic processes, namely the direct and the indirect processes.

Indirect process

In this process, butter is used as a raw material. Butter is melted, for instance in heated melting kettles or on rotating melting tables. The melted butter may be kept in a holding vat for some time to allow for part of the aqueous matter and the solids-non-fat to separate. After the fat has been decanted, or purified in a separator, the moisture that is still retained in the fat, is evaporated under vacuum.

Direct process

In this process, pure milk fat is made directly from milk, which is separated into skimmed milk and cream. The cream passes through a plant where it is concentrated to an emulsion with a very high fat content, which is broken up to obtain a liquid milk fat containing about 15% plasma. Thereafter, pure milk fat is obtained by a process of separation and vacuum drying.

Semi-direct processes have been developed, using equipment for continuous butter making.

If pure milk fat is manufactured from sour cream or sour-cream butter, neutralization is necessary. The required amount of neutralizer must be added to the cream in the direct process or, in the indirect process, to the melted butter, prior to separation.

As mentioned before (Section 5.4), anhydrous milk fat for recombining should be of very high quality. It must have been manufactured either from excellent-quality fresh cream, or from first-grade sweet-cream butter. If butter is used, the pH of the serum should be higher than 6.1, and the milk fat should be manufactured no longer than one day after the butter has been produced. In the manufacturing process, the raw materials and the milk fat should not come into direct contact with steam. The milk fat should be cooled to at least 22 °C before it is packed in an inert gas, in tins or vats which must then be hermetically sealed. The fat content of the anhydrous milk fat should be no lower than 99.9%; flavour and odour should be absolutely pure. The fat may not show signs of hydrolysis or oxidation.

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9 Cheese

9.1 Definition and description of cheese

Definition

Cheese is the fresh or matured product obtained by draining after coagulation of milk, cream, skimmed or partly skimmed milk, buttermilk or a combination of some or all of these products (definition: Code of Principles FAO/WHO).

Stricktly speaking, products made from whey do not fall under this definition. Like processed cheese, they belong to a separate category.

The product obtained by processing the coagulum mentioned in the definition can either be marketed as fresh cheese or be ripened for a shorter or longer period, and sold as matured cheese. To distinguish this type of cheese from processed cheese (Section 9.4) it is sometimes called 'natural cheese'.

Classification

Cheeses can be classified according to various principles, but none of the systems of classification is completely satisfactory. Classification according to the species that produced the milk is obvious, but it is impossible to differentiate the vast number of cheeses that can be produced from one kind of milk; moreover, it is possible to produce one variety of cheese from different kinds of milk.

Cheese may also be classified according to fat content (Table 13). This system also has shortcomings, because cheeses with the same fat content may show completely different characteristics.

Another system is based on the consistency of the cheese (Table 14). This system, like systems based on the water content in the fat-free cheese, gives rise to a great deal of overlap.

All the systems of classification mentioned so far are exclusively based on the characteristics of the final product. Classification is also possible according to the method of processing in general, or according to the ripening in particular (Table 15). In the event of internal ripening, cheeses mature by the activity of micro-organisms present within the cheese; in the event of surface ripening, organisms on the surface of the cheese contribute to its ripening.

Processed cheese

Processed cheese is made by grinding, mixing, melting and emulsifying one or more varieties of cheese, with the aid of heat and emulsifying agents and with or without

Table 13. Classification of cheese based on the fat content in the dry matter.

Classification	Fat content in dry matter (%)
High fat (or fat)	more than 60
Full cream	45 – 60
Half fat	25 – 45
Low fat	10 – 25
Skimmed	less than 10

Source: FAO/WHO, 1973. Standards for cheese.

Table 14. Classification of natural cheese, based on consistency.

Category	Description
Hard cheese	mainly sliceable cheese when little matured mainly grating cheese when fully matured
Semi-hard cheese	sliceable cheese at all stages of maturing
Soft cheese	sliceable or spreadable cheese according to variety and maturing stage

Source: Burkhalter, G., 1968. Definitions of cheese consistency types. Annual Bulletin II, Document 39. IDF.

Table 15. Classification of natural cheese based on the ripening procedure.

Fresh cheese
Bacterially (enzymatically) ripened cheese – mainly surface ripened – mainly internally ripened
Mould-ripened cheese – mainly surface ripened – mainly internally ripened

the addition of milk components. Spices and other foodstuffs may be added, in which case these additives should be mentioned on the packaging.

Whey cheese

Whey cheeses are the products obtained by the concentration of whey and the moulding of concentrated whey with or without the addition of milk and milk fat (definition: Code of Principles FAO/WHO).

Cheese manufacture under tropical conditions
The manufacture of cheese under tropical conditions encounters a number of difficulties, such as:
– the bacteriological quality of the milk may be low;
– the quantities of milk available are often small, and the supply for liquid consumption has priority;
– the conditions of high relative humidity and low temperature required for the proper ripening of most cheese varieties are difficult to realize;
– during distribution, the product may be exposed to high temperatures, which promotes a rapid deterioration of the product.
For these reasons, cheese production under tropical conditions is limited, and mainly restricted to fresh types of white cheese, although the adaption of certain techniques has led to products with a reasonable or good keeping quality.

With the establishment of modern plants, the conditions of processing and ripening can be sufficiently controlled for the successful production of cheese, but the quality of the milk and poor marketing conditions may still limit the possibilities.

Fresh cheese. The fresh cheese varieties have a limited keeping quality and should generally be consumed within a couple of days or one week after manufacture, depending on the storage conditions. Fresh cheese may be produced from acid- or rennet-coagulated milk or buttermilk. Whey may be expelled by working the curd or merely by hanging up the curd in a cloth to drain. The curd may be pressed mechanically or by hand into various shapes and sizes.

Since many cheese varieties are consumed both as fresh cheese and in the form of cheese that has undergone some kind of maturing, this category will not be discussed separately.

It is not intended to discuss as many cheese varieties as possible. The reader should consult one of the specialised handbooks for this information. Below, only the general basic procedures of cheese making will be discussed, illustrated by a few examples that are well known in tropical or sub-tropical countries.

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9.2 Principles of cheese making

Although there are hundreds of cheese varieties with distinct differences in appearance, taste and flavour, almost all of them are processed in five basic stages:
- preparation of the milk;
- coagulation of the milk with acid or enzymes;
- separation of whey to obtain curd;
- processing of the curd;
- ripening of the cheese.

Often certain other processes have been applied. Variations in these basic processes are responsible for the differences between the various cheese varieties. Cheeses produced in different parts of the world and known under different names are often produced in a very similar way.

In many cases, immigrants, international dairy companies or other parties have introduced European varieties of cheese in other parts of the world, with or without modifications to the processing techniques. Sometimes, these cheese varieties still bear the original name, in combination with the name of the country of production, like Queso Emmental Argentino, or were given a new name, like Queijo Prato (Brazil), a cheese similar to Gouda cheese and probably of Dutch origin.

9.2.1 Preparation of the milk

Poor conditions of milk production and milk handling give rise to a considerable contamination of the milk and the presence of dirt in the milk. For these and other reasons, the milk must be prepared, to make it suitable for cheese making.

Clarifying the milk
The visible dirt in the milk can be removed by sieving, filtering or centrifugal clarifying. This should be done in such a way that the bacteriological quality of the milk does not suffer (Section 5.3).

Addition of salt
The anxiety to protect the milk against bacteriological deterioration has in some cases led to the practice of adding salt to the milk before coagulation. Salt then exerts its antiseptic action right from the beginning of cheese manufacture, but the acidification of the milk and the curd is slower and it is more difficult to separate the whey from the coagulum. Typical examples of cheese produced by this procedure are the Egyptian cheese varieties Domiati and Danni cheese, originally made from cow's and buffalo's milk, and ewe's milk, respectively. On average, about 5 to 7% of salt is added to the milk. Thereafter, the milk is renneted at a temperature of about 32 °C, which takes two to three hours. The coagulum is ladled into moulds or rectangular frames placed on mats or wooden boards, where the coagulum is allowed to drain for a couple of days. Small moulds are turned twice a day. Pressure is applied on the coagulum in the

larger frames. The cheeses may be consumed fresh or after pickling, that is keeping them in brine for longer periods (e.g. over a month).

Neutralizing the milk
It is not advisable to neutralize high-acidity milk with sodiumcarbonate or bicarbonate for the production of rennet-type cheeses, since this badly affects the rennetability of the milk and changes the ripening procedure of the cheese. Neutralization of milk destined for acid-coagulated cheese will not cause problems from a technological point of view.

Standardizing the milk
Before cheese making, some cream may be separated, to be used for the production of butter and ghee. Legal standards for the fat content on a dry-matter basis have been set nationally and internationally for various cheese varieties and this usually implies standardization of the fat content (or rather the fat:casein ratio) of the milk.

Pasteurization
Cheese milk is pasteurized to kill any pathogenic bacteria and to reduce the number of spoilage micro-organisms and bacteriophages that may attack the starter bacteria. In some countries, the pasteurization of cheese milk is obligatory.

Intensive heating of milk prior to coagulation does not affect the acid coagulation, but reduces the rennetability of the milk. The latter can be restored – at least partly – by the addition of some calcium chloride. Pasteurization at high temperatures will also be harmful to the ripening of the cheese. It may produce a pronounced bitter flavour. As a result of the heat coagulation of the whey proteins, that thus will be incorporated in the curd, and an increased water-retention ability of the curd, high-temperature pasteurization gives higher yields.

Batch pasteurization at low temperatures (e.g. 62 to 65 °C for 30 minutes) may be applied without affecting the rennetability, but more bacteria will be killed with HTST pasteurization, e.g. 15 to 20 seconds at 72 to 74 °C. At these temperatures the cheese-making properties of the milk are still hardly affected, but thermotolerant bacteria will survive. If only small quantities of milk are available, batch pasteurization is the only possible system of heat treatment.

Modern techniques enable micro-organisms and spores to be removed by centrifugal force, sometimes named bactofugation (Section 5.3).

Removal of *Clostridium* spores is of particular interest, to prevent the defect 'late blowing' in some hard and semi-hard cheese varieties.

Applying hydrogen peroxide
The bacterial counts of milk can be considerably reduced by applying a hydrogen peroxide treatment that will have little or no effect on the rennetability. The quantity of peroxide to be added and the time of exposure depends on the contamination of the milk and the required results. A treatment of 30 minutes with 0.04 to 0.08% pure

*peroxide at a temperature of about 50 °C is practised, but other time-temperature-*combinations are also used. After treatment, the milk has to be cooled to about 30 °C, before the excess hydrogen peroxide is removed by adding catalase. Peroxide treatment may be combined with pasteurization, in order to destroy microbes that have survived pasteurization.

This process is not permitted in all countries, and some countries have laid down a limit to the quantity of the peroxide that may be added. Small quantities of hydrogen peroxide are believed to be harmless to man. Intensive treatment with this chemical may tend to prolong the time of renneting and to retard the contraction of the curd, which may lead to changes in the structure of the cheese.

Ripening the cheese milk

Some varieties of cheese are produced from milk that has been ripened for a certain period of time before the actual cheese making starts. Such ripening may also take place during the time milk is stored for creaming. A number of cheese varieties are manufactured from a mixture of fresh morning milk and milk from the previous evening that has been skimmed before being mixed with the morning milk. The ripening of milk involves the development of lactic acid bacteria and thus increases the acidity. This speeds up the renneting process. In modern processing techniques, the ripening procedure is controlled by storing the milk at a temperature of around 10 °C after 0.1 to 0.2% (or even more) of a starter has been added. Milk may be pasteurized before ripening. Techniques have been developed to leave out pre-ripening procedures, with the purpose of avoiding operational delays and saving storage space.

9.2.2 Coagulation of the milk

The second stage is to get the milk to coagulate or clot (i.e. to form a gel or coagulum). There are two ways of doing this: acid coagulation and rennet coagulation (Figure 57). Both procedures are practised in cheese making, but acid coagulation is almost exclusively applied in the manufacture of fresh cheeses, whereas rennet coagulation is applied in the production of fresh cheeses as well as cheeses that undergo a ripening process before consumption.

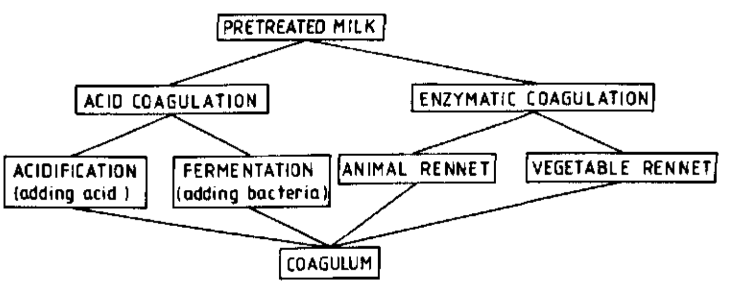

Fig. 57. Coagulation of milk.

9.2.2.1 Acid-coagulated cheese

The stability of the calcium-casein complex of milk decreases gradually as the acidity increases. At pH 4.6 to 4.7 the casein coagulates completely at room temperatures, though coagulation starts already at a pH of about 5.3. On the one hand, increased temperatures stimulate the destabilization and, on the other hand, they result in the formation of coarse casein floccules. Acid coagulation for cheese making can be achieved through acid production by lactic-acid bacteria, or by the addition of an organic acid such as citric acid, acetic acid or tartaric acid, or high-acid whey.

Mesophilic as well as thermophilic starters are used for the bacterial acidification of milk. The coagulation time depends on the kind of bacteria, the inoculation percentage and the temperature of incubation. Short-term and long-term coagulation, with setting periods of less than 6 hours and more than 12 hours, respectively, can be distinguished.

Two short-term methods are practised. One method uses 3 to 5% of a mesophilic starter, which completes coagulation after 5 to 6 hours' incubation at 20 to 30 °C. The other method uses 0.1 to 0.5% of a thermophilic starter, which completes coagulation after about 2 hours' incubation at 35 °C.

In the long-term process, milk coagulates after much longer periods, i.e. after 16 to 24 hours. Incubation takes place at a low temperature with a starter (usually mesophilic) at a rate of less than 1%.

Cottage cheese is a typical example of an acid-coagulated cheese. It is a granulated product, that is, not formed into a distinctive shape. Since manufacturing techniques differ considerably and a large variety of products is found under this name, only a general description of the production process will be given below.

Cottage cheese is produced from skimmed milk, either in the short-set method (4 to 6 hours) using 5% or more of a starter at about 30 °C or in the long-term method, using 0.5 to 1.0% of a starter at about 20 °C. The starters consist of mesophilic lactic bacteria. As soon as the gel is sufficiently firm, it is cut into small cubes of 0.50 to 1.25 cm, which are left undisturbed for 15 to 30 minutes, during which whey is expelled. Then the curd-whey mixture is slowly heated to 50 °C or even higher, while being stirred. Whey is drained off after heating and the curd is washed several times with water of decreasing temperatures, e.g. 25, 10 and 5 °C successively, leaving the curd in contact with the water for 10 to 20 minutes each time. According to the size of original cutting, small- or large-grained curd will be obtained. Sometimes a little rennet is used to obtain a firm curd, especially if a large-grained curd is required. Creamed cottage cheese (4% of fat) is manufactured by mixing the fat-free cottage cheese with cream of about 15% fat. The cream will be absorbed in a 24 hours' storage period at a temperature of 5 °C. Sometimes, salt and stabilizers are added. Cottage cheese has a poor keeping quality. Under conditions of hygienic manufacture, the product may be cold-stored for 7 to 14 days before it spoils.

Acid coagulation can be combined with a heat treatment, in which case the milk is heated to or close to its boiling point, either after acidification by lactic acid bacteria (as in the case of buttermilk), or during acidification by the addition of an organic acid. Chhana cheese (India) is an example of this type of acid-coagulated cheese. Milk is heated in an open vat and is taken off the fire as soon as it boils. Then an organic acid – often high-acidity Chhana whey – is added to the milk and the mixture is stirred until it coagulates. The curd is collected by straining the contents of the vat through a coarse muslin cloth, without the application of pressure. The pH of coagulation should be about 5.3 to obtain a product with the required smooth, butter-like texture. A lower pH gives a firmer texture. The temperature should not decrease too much during coagulation, nor should the pH of coagulation be too high, otherwise the product will be too soft and retain too much whey. The product is consumed fresh or it is used for the production of sweets like rasagollas (Section 10.1). The flavour is influenced by the kind of coagulant used. The keeping quality is limited, but may be extended by salting.

A similar acid-coagulation procedure is followed in the production of several varieties of Queso Blanco (Latin America). The curd for the production of this type of cheese is usually salted – sometimes after grinding – and pressed into loaf of various sizes and weights. A number of fresh rennet-coagulated cheeses are also sold under this name.

Curd obtained by heating buttermilk may be consumed fresh or be preserved, for instance by drying. Examples are Gamid (Arabian Peninsula) and Kashk (Iran), produced by mixing or kneading buttermilk curd, derived from ewe's or goat's milk, with salt, to form small balls, which are dried in the sun.

9.2.2.2 Enzyme-coagulated cheese

Several enzymatic coagulants (rennets) are used in cheese making. They can be of animal or vegetable origin (Table 16). Rennets have two activities in cheese making:
- to coagulate the milk,
- to break down protein in the cheese, thus contributing to the ripening process.

Rennin or chymosin
The principal animal enzyme is rennin or chymosin. Rennin is most widely used. It is found in the stomach (abomasum) of suckling calves. Bovine rennet is obtained by extraction of these stomachs in a 5 to 10% salt (sodium chloride) solution to which a preservative (e.g. boric or benzoic acid) is added. After extraction, the salt content is usually increased to 10 to 20%. After clarification of the extract the enzyme must be activated, because part of it is present as an inactive precursor, named prorennin or prochymosin. This is achieved by adjusting the pH to between 4.7 and 5.0. After activation, which takes about 5 days, the pH is adjusted again, this time to about pH 6.0, because at this acidity the activity of the rennet does not decline during storage. In the mean time, the strength of the rennet is standardized. The rennet should be protected against light; the best storage temperature is below 10 °C. As the calf grows older, the production of chymosin decreases and the production of pepsin in-

Table 16. Milk-clotting enzymes.

Animal	chymosin pepsin trypsin
Vegetable	ficin papain bromelin
Microbial – fungi	*Mucor pusilus* *Mucor miehei* *Endothia parasit*
– bacteria	*Bacillus subtilis* *Bacillus cereus* *Bacillus polymyxa*

After: Phelar, J.A., 1977. Milk coagulants; a critical review. Dairy Industries International 42(2)50.

creases in the stomach. For this reason, bovine rennets contain chymosin and pepsin; in high-quality rennets the ratio is about 80:20.

The optimum temperature for coagulation (renneting) is about 40 °C, but in the manufacture of cheese a renneting temperature of 30 to 32 °C is most commonly applied, because at that temperature the properties of the coagulum are considered most suitable for cheese making.

Only in a few cases is the rennet produced by the cheesemaker himself; usually by the extraction of dried cleaned stomachs in brine or acid whey. The strength of such rennets is only empirically known; the keeping quality of these rennets is usually poor. Sometimes, the stomachs are kept after cleaning, salting and drying. The dried stomachs are easy to transport and are used by some nomadic tribes; in cheese making a piece of dried stomach is added to the milk, as in the production of Ekt cheese (Arabian peninsula).

Most rennet used in cheese making is manufactured in specialized factories. The strength of these rennets is expressed as the volumetric quantity of cow's milk that can be brought to curdling by one volumetric quantity of rennet at 35 °C in a period of 40 minutes. Note that the method of testing the strength of a rennet must be standardized, because a number of factors, such as the type and quality of the milk, play a role. Commercial rennet is available as a liquid, or dried as a powder or compressed to tablets. The dried rennet is more resistant to high temperatures (over 100 °C) than the liquid rennet, which loses its activity quickly at temperatures of 55 °C and higher. Tablets are easy to handle and to dose. The strength of the dried forms is usually 1:100000, that of the liquid form 1:10000.

Substitute rennets

The increasing demand for rennet may coincide with a shortage of sufficient stomachs from suckling calves because more calves are grown for meat production. For this reason and to find a cheaper substitute, other coagulants have been introduced. The most important animal substitute is pepsin. Bovine pepsin derived from the stomachs of adult cattle gives better results than porcine pepsin, which can only be used if equal quantities of calf rennet and pig rennet are mixed. Chicken pepsin seems to be the least suitable of the three. Rennets obtained from the stomachs of sheep, goats and buffaloes are used for certain cheese varieties with satisfactory results. In general, it is not advisable to substitute other animal rennets for calf rennet, even if coagulation is acceptable. Major differences manifest themselves during ripening of the cheese, resulting in a product that is inferior to or at least different from the product normally produced. Hindu's may not accept cheese produced with calf rennet.

Since vegetarians object to cheeses produced with animal enzymes, or because such enzymes are not available or too expensive, much interest is being shown in vegetable rennets. Extracts from various plants, like *Ficus* (ficin from the fig tree), *Papaya* (papain) and *Bromelia* (bromelin from the pineapple) are or have been used, with rather unsatisfactory results. The major objection to vegetable rennets is their extreme proteolytic activity, which results in extremely bitter tastes. There are a few exceptions to this general rule, such as the production of Queijo da Serra (Portugal) and a few cheese varieties in West Africa with a coagulant consisting of the flower of *Cynara cardunaculus* (a plant related to the artichoke) or similar coagulants.

Rennet produced from bacteria shows excessive proteolysis as well, and the quality of cheeses produced with these coagulants is generally reported to be poor.

The best results with substitute rennets are obtained with those produced from moulds, mainly belonging to the genus *Mucor.* Some fungal rennets have proper coagulating and ripening properties without causing the defect bitterness, but they have not been universally accepted, because of the fear that the cheese produced will differ in quality from the original product manufactured with calf rennet. Moreover, it is not yet absolutely clear whether the fungal substitutes can be used in the manufacture of one particular variety or group of varieties of cheese, or whether they can be used as all-purpose substitutes under various conditions.

Renneting the milk

κ-casein prevents the other caseins from precipitating. The κ-casein is proteolysed by the action of chymosine; this results in a destabilization of the caseinate complex, thus forming an insoluble part, the para-caseinate, and a soluble part, the whey proteose. As a result of the destabilization of the κ-casein, the milk clots and a gel is formed. This gel gradually contracts (syneresis) under the expulsion of a liquid (whey), which contains most of the dissolved milk components and proteose. The contracted gel, the curd, contains the para-caseinate, enclosing most of the fat. The curd still contains part of the liquid containing dissolved milk components and proteose.

Before it is added to the milk, liquid rennet may be diluted, to facilitate an even distribution. Powdered rennet and rennet in tablets must be dissolved in water before being added to the milk. As it easily loses strength when diluted, rennet should not be dissolved and diluted until immediately before it is to be used.

The amount of rennet used depends on the views of the cheesemaker, the type and quality of the milk, and the cheese variety to be produced, but as a rough indication it may be assumed that for the manufacture of semi-hard cheese varieties, 12 ml rennet with a strength of 1:10000 or 8 ml with a strength of 1:15000 must be added per 100 l milk. The renneting time of milk is inversely proportional to the amount of rennet added and to the strength of the rennet.

Rennet is normally used in combination with a starter. Sometimes, a starter may be added a considerable time before the rennet, to allow the milk to preripen, but in most cases the starter and rennet are added one after the other.

The main reason for adding a starter is to ferment all the lactose and to lower the pH. Starter bacteria also play an important role in the ripening of the cheeses. Mesophilic or thermophilic starters are used (depending on the temperatures applied during the manufacturing process). Some varieties of indigenous cheese are produced without the addition of a starter. In these cases, it may be assumed that the 'natural contamination' of the milk guarantees a sufficient lactic-acid production.

Renneting starts immediately after starter and rennet have been added to the milk. The renneting time is the time that lies between the moment the rennet is added to the milk and the moment the first signs of coagulation are visible. This time depends – as explained already – on a number of factors, such as the type of milk.

Buffalo's milk coagulates quicker than cow's milk and the curd retains less whey under identical conditions. This leads to a harder type of cheese with a drier and more crumbly texture. *Several modifications to the manufacturing process* used for cow's milk have been suggested if the same variety of cheese must be made from buffalo's milk; these include using less rennet, diluting the milk with water and adjusting the cheesemaking process in such a way that more whey is retained in the curd.

The renneting process does not stop at the moment a gel has been formed. Curd formation starts by contraction of the gel and expulsion of whey (syneresis).

9.2.3 Separation of whey to obtain curd

The amount of whey that has to be expelled from the coagulum will largely depend on the variety of cheese to be produced. In general, cheeses that are consumed fresh *or after a short ripening period* must retain more moisture than cheeses that will ripen for extended periods, like the hard and semi-hard varieties. Moreover, cheeses with a high moisture content will ripen quicker than cheeses with a low moisture content. To promote whey expulsion, the coagulum is worked as soon as it is sufficiently firm.

There are several methods of draining the curd, i.e. of causing whey to be expelled:
- drainage in cloth,
- drainage in moulds,
- cutting and stirring in the cheese vat, often followed by pressing in moulds.

For the production of certain cheese varieties, the coagulum is ladled directly into a cloth or a mould immediately after it has reached the required firmness.

Drainage in moulds
To promote drainage, the moulds, which are usually cylindrical and have no base, are perforated. The open moulds are placed on mats during filling and drainage. In the production of some varieties, the moulds with their contents are turned several times. This system of drainage is practised in the production of many surface-ripened cheeses, for example, Camembert (France).

The volume of the coagulum in the moulds may be reduced to one-third as a result of whey expulsion, before a sufficiently firm loaf is obtained, which is suitable for further processing.

Drainage in cloth
A simple piece of cloth may be folded in such a way that it can hold the coagulum, or the cloth may be sewn into a bag. While draining, the cloths with the coagulum may be put on a table or on the floor, or they may be hung up to drip. This method of draining the coagulum generally results in cheese varieties with high moisture contents.

Cutting the coagulum
Expulsion of the whey is greatly promoted by increasing the surface area of the coagulum. This is achieved by cutting the gel or coagulum into smaller pieces.

The most primitive ways of cutting are stirring the coagulum by hand or by using wooden sticks, paddles, knives or similar implements. Cutting should be done with sharp knives, in a careful, gentle way, and after the coagulum has acquired the proper firmness. If cutting is done roughly, with blunt instruments, or if the coagulum has not yet reached the proper consistency, too many very fine curd particles will be liberated, forming the so-called fines, which will later escape with the whey. This results in low cheese yields. Whey with a low content of fines will have a clear, greenish-yellowish appearance. High contents of fines will give the whey a whitish appearance.

For complete control of the cheesemaking process it is important to cut the coagulum in equal-sized, small cubes. These allow for uniform whey expulsion and uniform cooking in a later stage of the operation. If large lumps of curd remain, they will retain a high content of whey and the cheese obtained will have an uneven distribution of moisture and hence of pH and consistency.

The best way to control uniform cutting of the coagulum is to use special 'cheese knives'. These knives consist of a frame with wires or knives, which should not be too blunt. They are mounted horizontally or vertically. The distance between the knives or wires may vary considerably, e.g. between 5 and 50 mm but is mostly between 10 and 20 mm. The coagulum can be cut into uniform cubes by driving the horizontal cheese knife carefully through the coagulum, and then cutting down with the vertical knife in two perpendical directions, thus forming successively uniform layers, strips and cubes of curd. The size of the cubes is one of the factors determining the moisture content of the cheese. Smaller cubes will generally give cheese with a lower moisture content, but the curd may be difficult to drain properly if the particles are very small, and this will result in higher water contents.

If the cheese is being made by hand, the cheesemaker can exercise almost total influence on the cutting procedure. In mechanized working of the coagulum, the formation of the curd blocks depends to a large extent on the cutting mechanism of the equipment. In the case of round cheese vats (Figure 58) with a mechanical cutting device, the knives usually have a rotary movement and in the case of rectangular vats the movement may be pendular or planetary. The latter system of movement can also be applied in very large round vats. Care should be taken to ensure that the curd near the walls of the vat is cut properly. The cheese knives are often interchangeable and may operate at different speeds. Cutting always starts at the lower speeds, to avoid excessive formation of fines.

After cutting, the whey-curd mixture is usually left undisturbed for a while. During this period the curd pieces contract and expel more moisture, in the meanwhile becoming firmer, although still being soft. After the period of rest, the cheesemaking operation can be continued along various lines.

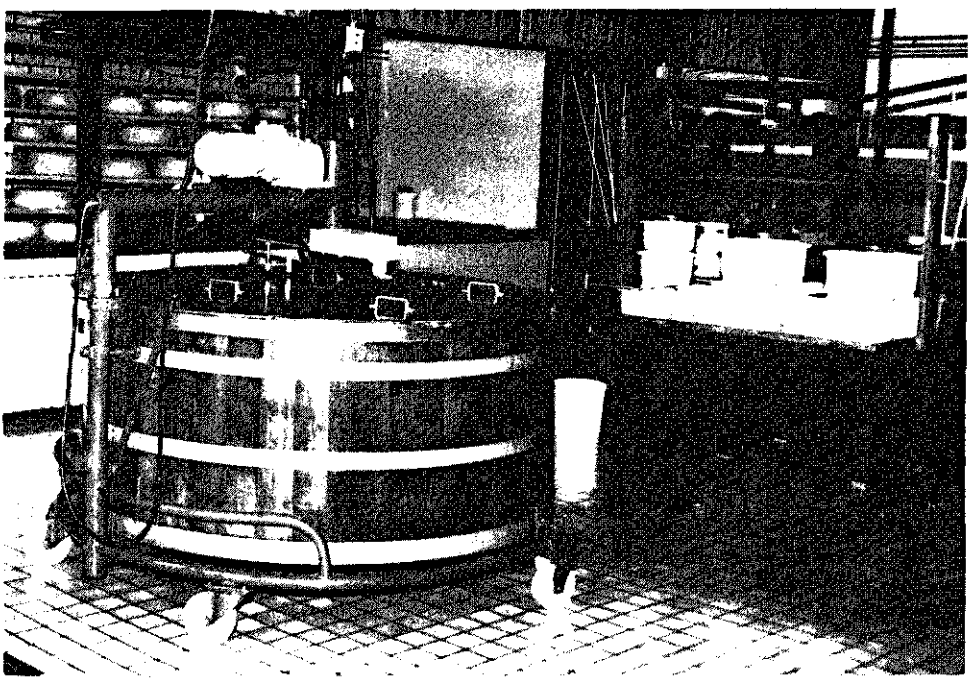

Fig. 58. Cheese vat (teak wood) in small-capacity cheese factory. At the right side, cheese moulds of various size; at the background Gouda cheeses on shelves. Photo: H. Oosterhuis.

In one method the expelled whey is removed from the cheese vat and the remaining curd – still containing much moisture – is put into cloths or moulds to drain further. The drained curd can then undergo different treatments.

In a different procedure, more whey can be expelled in the cheese vat by stirring the whey-curd mixture after cutting. At first, the mixture is stirred gently, so that the curd particles, which are still very soft at this stage of the operation, do not disintegrate further. The stirring can be gradually intensified as the firmness of the particles increases. The whey-curd mixture has to be stirred so that the particles do not settle and stick together, which would hamper whey expulsion and would result in an inhomogeneous curd. Moreover, the frequent collision of the particles promotes whey expulsion. To intensify the stirring and colliding action, some of the whey may be drained off after stirring has proceeded for some time. After stirring and drainage, the 'dry' curd can undergo various treatments.

Cooking the curd

Cooking (or scalding) the curd, which may take place during the process of stirring, does not actually mean that the whey-curd mixture is heated to its boiling point. It merely means increasing the temperature to a moderate level. The purpose of the temperature increase is to enhance syneresis and consequently to promote whey expulsion. In many cases, the temperature is only increased to the original temperature of renneting. Higher temperatures, for instance to 40 °C (medium cooking), and 50 °C (high cooking) are also applied, the latter especially in the production of hard varieties of cheeses using starters with thermophilic bacteria, which survive higher temperatures than mesophilic bacteria, and which are particularly active at these higher temperatures. Temperatures over 50 °C should be avoided because of the risk of damaging the starter and the rennet.

The cooking temperatures applied when making low-fat cheeses are usually a few degrees Celsius lower than those used when making full-cream cheeses. In this way, less whey is expelled when making low-fat cheese; this allows for a slightly higher water content and consequently a smoother texture, which is more comparable with that of cheeses with a higher fat content.

Depending on the type of cheese and the equipment available, two different methods are applied to increase the temperature of the curd-whey mixture:

- the addition of hot water or steam injection;
- the introduction of hot water or steam in the double jacket of the cheese vat.

The addition of hot water is an easy method, applicable in small-scale operations, e.g. on farms. The water can be heated on a stove and added to the cheese vat using buckets or similar containers. The temperature of the water usually varies from 40 to 85 °C. For direct heating with steam, a steam pipe has to be inserted into the cheese vat if there is no fixed connection. Since a steam generator is required, this system is not applicable to small-scale operations.

Adding water to the curd, that is washing the curd, often has another objective as well, because it is a way of influencing the acidity and consequently the characteristics of the curd. The added water will lower the concentration of the dissolved components of the whey and the curd. A lower lactose content in the curd will result in a lower acid production. This form of loss of lactose can be limited by cooking the curd by steam injection instead of by adding water. In this case, only the condensed steam will lower the concentration. Cooking the whey-curd mixture by heating it in a vat with a jacket through which warm water or steam is circulated will prevent this form of lactose loss.

To avoid over-heating, cooking should be done carefully and the contents of the cheese vat should be stirred continuously. The temperature should not rise too quickly, because quick heating stimulates the formation of a skin on the surface of the curd particles, which hampers whey expulsion. After cooking, stirring is continued for some time to expel more whey, which can be drained from the cheese vat between times. A second cooking may take place.

9.2.4 Processing of the curd

At the moment the curd is sufficiently dry for the variety of cheese to be made, it is formed into cheese-loaves, or processing is continued in another way. The first-mentioned procedure is followed in the production of a number of hard or semi-hard cheeses *with so-called internal ripening* (Section 9.1), such as Gouda cheese (the Netherlands), Emmental cheese (Switzerland) and Parmesan cheese (Italy).

In the manufacture of Gouda and similar cheeses, a starter containing mesophilic lactic acid bacteria, and sufficient rennet is added to the milk to coagulate it in about half an hour at 30 °C. After cutting, the curd is stirred in the cheese vat for about one hour, during which part of the whey is drained off, and the curd is cooked once or twice at a temperature of about 35 °C. The curd is pressed in cloth-lined moulds and the cheeses are salted in a brine solution of about 15 to 20%. The length of the periods of pressing and salting mainly depends on the weight of the cheeses. The cheeses should ripen for at least 6 weeks at a temperature of about 15 to 16 °C before consumption, but ripening periods up to 9 months are quite common.

The curd for Parmesan cheese is worked much drier than that for Gouda cheese, mainly by applying a slightly higher renneting temperature (35 °C) and a distinctly higher cooking temperature (50 °C and higher). Moreover, the total working time in the cheese vat is longer. To withstand the high cooking temperature, a starter containing *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (and/or *helveticus*) is used. After pressing, the cheese is salted in a brine (of about 25%) for about a fortnight, after which the cheese is allowed to ripen for 10 to 24 months. Like Cheddar cheese and contrary to Gouda cheese, the texture of the cheese is completely closed; that is: it has no holes.

Gouda cheese has a few small holes, so-called eyes, principally produced by citrate-fermenting and thus carbon dioxide-producing lactic acid bacteria. Emmental cheese is renowned for its numerous holes, which have diameters of 1 cm and more. The holes are produced by propionic bacteria, which are present in the starter together with

Streptococcus thermophilus and *Lactobacillus bulgaricus* (and/or *helveticus*).

For Emmental cheese, the milk may be pre-ripened by a mesophilic starter, before rennet and the thermophilic starter are added. Renneting takes place at 35 °C, after which the coagulum and the curd are worked intensively for more than two hours. The cooking temperature is 50 °C and sometimes even slightly higher. The dry curd is lifted from the cheese vat in a cloth and pressed in hoops for about one-and-a-half days, followed by salting in a brine bath for two or three days. Thereafter, the cheeses are ripened for about two weeks at a low temperature (10-15 °C) followed by three to six weeks at an elevated temperature (20-25 °C) to allow for the production of holes. Finally, the cheese is kept at a temperature between 5 and 10 °C for 4 to 11 months to allow the flavour to develop.

Many variations in the processing techniques are practised, either leading to the same result, or to varieties that only show similarity to the cheeses discussed above.

All hard and semi-hard varieties with internal ripening require milk of very high quality and properly controlled ripening conditions (moderate temperature and high humidity). These varieties are also characterized by an intensive treatment of the curd in the cheese vat. As a rule, a drier and harder cheese will be obtained if the coagulum is treated more intensively, e.g. by cutting the coagulum finely, stirring the curd for longer and using a higher cooking temperature. Prolonged ripening (causing moisture loss by evaporation) contributes to the firmness of the cheese.

Instead of forming the dry curd directly into cheese loaves after it has been stirred in the cheese vat, processing may be continued. The most important processes are:

- ripening the curd in the cheese vat,
- heating the curd,
- pressing the curd,
- salting the curd.

Ripening the curd

After the whey has been drained off, the curd may undergo a special ripening procedure before processing is continued. The major characteristic of this procedure is a further increase of the acidity of the curd, combined with expulsion of whey. As a result of the increase in acidity, the para-caseinate will lose part of its calcium, thus obtaining a less elastic, more crumbly texture. There are several ways to perform this process of ripening, named cheddaring. The process originally followed in the manufacture of Cheddar cheese was to cut the flat cake of curd particles that had settled and stuck together at the bottom of the cheese vat, into blocks or slabs. These were piled (heaped) and repiled to excercise some pressure upon the curd and to slow down the rate of cooling. This promoted a uniform ripening and whey expulsion. Sufficient space had to be left between the blocks or slabs to allow all the whey to drain off.

Ripening or cheddaring may take place in the cheese vat or on tables or in other suitable places. Sometimes, extra weights are placed on the curd to exert some pressure during ripening. The curd is covered with bags or cloths to prevent it from cooling too quickly. At the moment the ripening process is completed, the curd is milled or crumbled and ready for further processing.

The rate of acid development, and thus the cheddaring process, is much faster in the curd of cow's milk than in that of buffalo's milk; this can be explained by the higher buffering capacity of buffalo's milk.

In the production of Cheddar cheese, a dry curd is produced, partly because a rather high cooking temperature is used. After cheddaring, that is at the moment the curd has reached a pH of about 5.2 or lower, the curd is milled, and mixed with 1.0 to 2.0% of salt. Thereafter, the curd is put into large cloth-lined hoops and is pressed for 16 to 24 hours at a pressure that is gradually increased to about 4 atm. The cheese is ripened in an environment of 2 to 15 °C and a humidity of about 85%. After 6 to 12 months the cheese is ready for consumption, that means it has developed a rather dry (about 38 to 40% moisture) crumbly, but closed texture and a somewhat sharp flavour.

Many variations in the processing technique have been developed to shorten the ripening period or to obtain variations in flavour.

Heating the curd (heat-processed cheeses)

The characteristic of the heat-processed cheeses – often called the 'pasta filata' (Italian for 'shredded paste') cheeses – is that the curd is heated after it has reached a pH of 5.1 to 5.3 by some kind of cheddaring process. This curd is milled or otherwise divided into pieces, which are heated in hot (70-90 °C) water, brine or whey. The hot or warm curd becomes soft and is plastified by a process of kneading, mixing, moulding and stretching. After complete plastification, smaller or larger portions of the curd are formed into cheeses of various shapes. Moulds may be used for this purpose, as in the production of Kaşar cheese (Turkey) and Kaskaval cheese (Balkans). Other cheeses of this type are made by pulling the plastic curd into ribbons (Figure 59) which are then rolled up, e.g. Queso Palmito (Costa Rica), or by making rolls which are cut into pieces. The rolls or the pieces are formed into the required shape, which may be round, pear-shaped, etc., e.g. Provolone (Italy).

Heat-processed cheeses are salted in different ways; for instance by adding salt to the plastified curd, by placing the cheeses in brine, by sprinkling salt on the cheeses, or rubbing the cheeses with salt.

Although the cheese may be stored for ripening, like the Kaşar and similar cheeses, some varieties are consumed fresh. The heating of the curd, which destroys many bacteria, and the possibility of consuming the cheese fresh, are advantages under tropical conditions.

Pressing the curd

The pressing of the curd is part of the manufacturing process of most cheese varieties, but it is accomplished in different ways. After coagulation, the coagulum is either ladled directly or after a rough cutting into moulds or cloths, or it undergoes some kind of processing in the cheese vat before being transferred to the moulds (see previous section).

Moulds are made of wood, plastic or metal and come in various shapes; they may

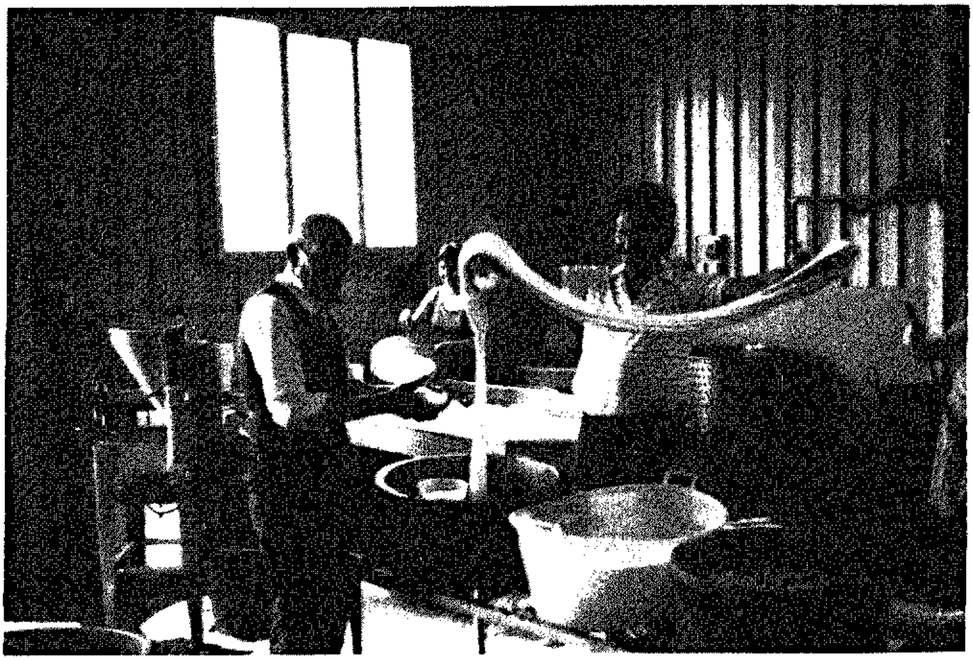

Fig. 59. The manufacture of pasta filata cheese. Photo: M.A. Luijkx.

be round or rectangular, with or without a bottom and a lid. Moulds with a bottom usually have drainage openings in the bottom and sometimes in the sides. Those without a bottom are usually placed on a drainage mat. Moulds are often lined with a cheese cloth; sometimes a separate cloth is used. The cloth promotes drainage of whey and the formation of a rind (Figure 60).

The curd in the mould undergoes a process of pressing. In some cases it is pressed by its own weight, which is intensified by the contraction of the coagulum as a result of the action of the rennet. This gives the impression that the coagulum merely sags, e.g. in Surati paneer (India). Other cheese varieties are pressed by stacking a number of cheeses on top of each other after they have obtained their shape and have become sufficiently firm in the moulds, e.g. Kaşar cheese (Turkey). To avoid differences in pressure, the vertical order of the cheeses is changed at regular intervals. Some systems make use of weights that are put on top of the cheese or on top of stacks of cheeses. Such weights may be simple (stones, containers of water, etc.), or they may be specially designed cheese presses. In these cases the cheeses are normally covered with a lid to distribute the pressure evenly over the cheese or over all cheeses if a number of cheeses are pressed simultaneously.

The main purposes of pressing cheeses are:

- to give the cheese a certain shape;
- to expel more whey;

Fig. 60. Examples of plastic cheese moulds. Courtesy: Arend B.V.

– to develop a firm closed rind; if applicable;
– to give the cheese a homogeneous structure (of special importance if the curd particles are very dry before pressing).

Soft cheeses, which have a high water content because the coagulum has scarcely been worked, if at all, in the cheese vat, are generally consumed fresh. Therefore, no protecting rind is required, and no or hardly any pressing takes place. The so-called hard and very hard cheeses, manufactured from a thoroughly worked dry curd, require long ripening periods and a proper protective rind. To obtain such a rind the cheese is pressed intensively. For smaller cheeses, intensive pressing may be found less important.

To promote whey expulsion and rind formation, the curd may be wrapped in a cloth before pressing starts. After pressing, the cloth is usually removed, but sometimes the cheese keeps its cloth (Cheddar cheese). Whey expulsion, uniform moisture distribution and rind formation can be promoted by replacing the cloth by a fresh one once or more times during pressing, and by turning the cheeses at the same time.

Sometimes, the curd is prepressed in the cheese vat, like Dutch cheese varieties, or on a special 'pressing table', like Beyaz Peynir (Turkey), after which it is cut into blocks. These blocks may be further pressed in moulds.

The temperature of the pressing locality should not be too high or too low, because whey expulsion is retarded if the cheese cools down too quickly and too much, but – on the other hand – too high a temperature may give rise to the development of cheese failures, especially gas formation, as long as not all lactose has been converted into lactic acid. The optimum temperature depends on the cheese variety.

Salting curd and cheese

With the exception of many fresh cheeses, cheese is normally salted. The salt contributes to the flavour and the taste of the cheese as such, but it also influences the ripening procedure and has a selective influence on the development of micro-organisms. Sometimes, salt contents are very high in order to retard the development of deteriorating bacteria. Salt also affects the texture of cheese.

The salt can be added to the milk as a preservative, but in most cases it is either added to the curd before the cheese is formed, or thereafter by immersing the loaves in a brine, or by rubbing them with salt or a saturated brine. When the loaves themselves are salted, it will take some time before the salt has penetrated into their centres. Adding salt to the curd before the loaves are formed has the advantage that the salt can perform its preservative action right from the start. But, on the other hand, it also retards acid formation, which may result in the development of defects.

Crumbling or even grinding the curd before adding salt will promote a uniform and quick salt distribution throughout the cheese. The exact quantity that is added is often not known, but it is generally equivalent to 0.5% of the original quantity of milk.

In the manufacture of some cheese varieties, like farm-made Queso Chanco (Chile) and Rahs cheese (Egypt) salt (2 to 5% in weight of the original quantity of milk) is added to the curd-whey mixture after the curd has already been treated rather intensively and part of the whey has been drained off. After the salt has been added, the treatment of the mixture is continued.

Double salting, that is adding salt to the curd and salting the cheeses again in brine is occasionally practised.

9.2.5 Ripening of the cheese

Curd has a rather high water content, even after it has been thoroughly worked. Therefore, curd and fresh cheeses are media in which several micro-organisms can develop. By controlling the environmental conditions in such a way that certain types of micro-organisms grow whereas others are suppressed, it is possible to ripen cheese in a particular way, and to give it a characteristic flavour and often a specific texture, especially if the desired micro-organisms are added during cheese making, as in the manufacture of blue-veined cheeses.

The production of a coagulum and a curd is hardly a problem under tropical conditions, but it is much more difficult to control conditions for a successful ripening of the cheese. Almost all cheese varieties require ripening temperatures below – and many of them well below – 20 °C, in combination with a high humidity. Hard varieties generally require a lower ripening temperature than soft ones. Only a few varieties ripen at a higher temperature, but then, the humidity of the air is usually very low, and the keeping quality of the cheese is limited. Under tropical conditions, the production of matured cheeses may only be successful in dairy plants with proper pasteurization facilities for the cheese milk and properly air-conditioned rooms for processing and ripening.

Ripened cheeses either belong to the mainly internally ripened varieties or to the mainly surface-ripened ones.

Internally ripened cheeses

To this category belong most hard and semi-hard cheeses, which have a firm closed rind that should be free from the development of micro-organisms, especially moulds and yeasts. For this purpose the cheeses can be treated with solutions of propionic acid (about 7.5%) or sorbic acid (about 0.1%) or with vegetable oils, like olive oil.

To prevent moulds from developing on the surface of the cheese and to reduce the loss of moisture, and consequently weight, by evaporation, cheese may be coated with wax or plastic. This is sometimes also done to give the cheese a more attractive appearance. Paraffin wax and waxes especially composed for the purpose are available. Usually the waxes are melted in a bath and the cheeses are submerged in the bath for a few seconds. After dipping, the wax on the cheeses is allowed to solidify. Waxing may be repeated as and when required.

Plastic coatings are applied in the form of a polymer dispersion. After the dispersion is put on the cheese (in small-scale operations this is usually done with a sponge) the dispersion is allowed to dry, leaving a plastic coating on the surface of the cheese. Coating is generally repeated at least once, or twice, depending on the period the cheese has to be stored. Coatings can only be applied successfully on clean and dry surfaces. Fungicides, which give an extra protection against mould development, may be added to the coatings.

A method has been developed to laminate blocks of fresh cheese with plastic films. The cheese ripens in the film, which takes over the function of the natural rind. Cheeses may be packaged by simple wrapping in a film, or by packaging in a special bag, which shrinks at elevated temperatures (heat shrinkage), thus covering the cheese tightly. By this type of cheese, losses are minimized, because there is no rind formation and no loss of moisture by evaporation. Moreover, maintenance of rindless cheese is easier.

Ripening of cheese is induced by the activity of enzymes that originate from the milk and the rennet, or which are produced by micro-organisms, such as lactic acid bacteria present in the starter. During storage, the flavour of the cheese changes; it becomes more pronounced and sharper, but this does not give rise to deterioration. Cheeses that are ripened internally usually have a very long keeping quality.

Differences in ripening can be observed in cheeses produced from different kinds of milk. Ripening in buffalo's milk cheeses is slower than that in cow's milk cheeses; the former hardly develop the flavour characteristic to cow's milk cheeses. Likewise, flavour development in goat's milk cheeses differs from that in cow's or buffalo's milk cheeses.

Surface-ripened cheese

The ripening of this category of cheese is mainly caused by enzymes produced by a specific flora that develops on the surface of the cheese, like mould-ripened Camembert and Brie (France) and bacteria-ripened Tilsiter (Germany). A number of the surface-ripened cheeses have a blue- or greenish-veined texture throughout the cheese, caused by mould (fungal) development. A culture of moulds is added to the milk before renneting, or to the curd before it is transferred to the cheese moulds or hoops. As moulds are aerobic, the structure of the cheese should be porous, to give the oxygen of the air access to the interior of the cheese. Porosity is partially obtained by using gas-producing starter bacteria. Moreover, the cheeses are pricked or stabbed with needles, thus making openings through which the air can penetrate, as in Roquefort (France) and Küflü Tulum Peyniri (Turkey).

Surface-ripened cheeses generally have a distinct, often brief period during which they are fit for consumption. Storage is only possible under properly controlled temperature and humidity. Otherwise, they easily deteriorate or dry out.

Some cheese varieties are ripened in the skins of sheep or goats, like Tulum Peyniri (Turkey). This variety is manufactured by amply salting crumbled curd, which is pressed into a skin. After the skin has been sewn up, the cheese is left to ripen for 3 to 4 months at a rather low temperature, preferably below 10 °C.

9.2.6 Special processes of preservation

As mentioned already, cheeses require a controlled temperature and atmospheric humidity for ripening and preservation, and special treatment may be required. If no proper conditions for ripening and preservation exist or can be created, and the product is not consumed fresh, special ways of preservation are practised, such as:
- drying,
- smoking,
- pickling.

Drying cheese
Some cheese varieties are dried for preservation. They are only of local and limited importance. The curd for these varieties may be obtained by renneting milk, but generally consists of drained sour milk or buttermilk. A typical example is Zurpi cheese (Nepal), manufactured from curd, obtained after heated buttermilk has been drained. The curd is kneaded into ribbons, which are dried on the roof or over an open fire. Kīshk (Egypt) is another example. Sour milk or buttermilk is drained in a cloth, in a porous leather bag or in a porous earthenware pot. After being drained the curd is mixed with salt and kneaded into small balls, which are dried. These dried products, which could be classified with the fermented milk products as well, are very hard and can only be consumed after grating, for cooking and similar purposes. Nevertheless, these products are easy to manufacture under primitive conditions, and their keeping quality is better than that of all other products produced under similar conditions. Moreoever, they are easy to handle.

Several advanced systems are used for the industrial drying of cheese, such as tray-drying, roller-drying, spray-drying and freeze-drying. The products thus manufactured have an excellent keeping quality and are often used in the food industry and in the household; although high drying temperatures greatly alter the flavour of the cheese.

Smoking cheese

Smoking is a way of preserving cheese. Typical examples are the Indian Dacca and Bandal cheeses. The former is manufactured from cow's milk with some buffalo's milk (if available), whereas the latter is made from a mixture in which buffalo's milk predominates over cow's milk, but in most cases, cream is used. The milk or cream is coagulated with rennet. Starters are occasionally used. For the production of Dacca cheese, the coagulated milk is broken up by hand and put into small wicker baskets. Expulsion of whey is stimulated by placing a board with weights on top of the baskets. When the cheese is sufficiently dry, it is smoked over an open fire. The cheese has a smoky flavour and can be kept for one to two months at the most. Bandal cheese is a similar product.

Smoking the cheese retards protein and fat decomposition, but the development of moulds on the surface is difficult to prevent in a humid atmosphere.

Cheese is smoked on an industrial scale to give the product a specific flavour. Smoked Cheddar and smoked Provolone are appreciated by many consumers. Smoked processed cheeses are also known. Special precautions should be taken to prevent the cheese being overheated during smoking. Artificial smoking, using 'smoke distillates', is also practised.

Pickling cheese

In the countries around the Eastern part of the Mediterranean, it is common to preserve cheese by storing it in a strong salt brine until it is consumed. The pickled cheeses are known under various names, like Feta (Greece), Beyaz Peynir (Turkey), Brinza (Israel), Jibneh (Arabian Peninsula), Sirene (Syria), etc.

The methods of manufacture of the curd or cheese before it is pickled vary widely. Most varieties undergo some kind of a cheddaring process. Sometimes, salt is added prior to pressing. Generally, the curd is transferred from the cheese vat to perforated wooden or metal rectangular frames with or without a detachable lid and bottom, which may be placed on a pressing table. Sometimes the curd is put in bags that are hung up to drain before it is put in the frames. In most cases the boxes (frames with bottom) are lined with cloth. After the box has been filled, the cloth is folded over the curd and the box is covered with a lid. Stones, containers of water or other heavy objects, are placed on top of the lid for pressing. Starting with a low pressure, which is increased gradually, diminishes the risk that the curd will stick to the cloth. After pressing, the curd has formed a solid block. This block is cut into pieces, which are salted by immersion in saturated brine, or by rubbing with salt. Thereafter, the blocks of white cheese are packed into earthenware pots, tins, plastic containers or bags, skins or other containers, which are filled with water, milk or whey containing salt in solutions of 8% up to saturation (more than 20%). The layers of cheese blocks in the containers are prevented from sticking together by sheets of parchment. The pickled cheese is ripened for a period varying from several weeks to several months, depending on the temperature of storage, the salt content, the required quality, etc.

If not all lactose has been fermented before the blocks of cheese are packed, gas formation by coliforms is quite common. The containers are not closed immediately, to avoid bulging. Severe coli infections may lead to a spongy texture.

The quality of pickled cheese at ambient temperatures can be considerably prolonged by heating the blocks of curd (if appropriate, in their packaging) or by plunging them for a short period in hot water before the final pickling. The consistency of the cheese is considerably altered as a result of this heating. The product is likely to become more compact and firm, even rubbery.

The cheese may lose a considerable amount of water, and consequently weight during storage in brine. Losses of 50% are possible. The drier the cheese and the higher the salt content at the moment of pickling, the lower the loss in weight will be. High temperatures increase the loss in weight. As a result of the loss of moisture and the absorbtion of salt, the cheese acquires a firm consistency. The pH of the cheese must be low, e.g. pH 4.7 to 4.8. The cheese will have a tendency to remain soft at higher pH's. Proteolysis of the protein during pickling contributes to the flavour of the cheese, but this process seems to be retarded if the salt content is too high.

Ewe's milk is generally preferred for the production of pickled cheese, because cow's and buffalo's milk give a bland-tasting cheese. As a result of the addition of goat's milk, the cheese will have a more piquant taste, but consumers may object if this flavour is very pronounced.

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9.3 Cheese additives

Apart from starters, rennet, moulds and salt, a number of other additives are used in cheese making. Below, only the principal ones will be mentioned. In many countries, the permissible amount of additives is legally prescribed.

Spices and herbs
Spices or herbs are added to certain cheese varieties; for example, cummin seeds to Leiden cheese (Holland), peppercorns to Sicille cheese (Tunesia) and herbs to Otlu Van Peyniri (Turkey). They give the cheese a particular taste and flavour.

Calcium chloride
Calcium chloride is added to the cheese milk in order to improve its rennetability, especially if the milk has been pasteurized or overpasteurized. Usually, not more than 25 g is added per 100 l of cheese milk.

Sodium and potassium nitrate
Nitrates are added to suppress gas production by coliforms and clostridia in a number of semi-hard cheese varieties. Excessive gas formation leads to too many holes in the cheese, followed by the blowing of the cheese.

Coliforms may produce gas as long as all the lactose has not yet been fermented by the lactic acid bacteria. This leads to the defect 'early blowing', but it can be prevented by the addition of nitrates, which have the ability of binding the gas (hydrogen) that has been produced.

Gas production by clostridia takes place in a later stage. The bacteria are anaerobic spore-formers, which are able to ferment lactates, producing the gases hydrogen and carbon dioxide. This defect is called 'late blowing'. Nitrites are able to suppress the development of generating clostridia spores.

Nitrates added to the cheese milk are converted into nitrites by the enzyme xanthine oxidase, which is present in milk that has not been heat-treated too intensively. Usually, not more than 15 g of the nitrate is added per 100 l of cheese milk. To limit the amount of this additive it is often used in combination with the centrifugal removal of micro-organisms, in this particular case the clostridia (Section 5.3).

Colouring agents
Dyes are added to the cheese milk to give the cheese a yellow or an orange colour. In most cases annatto or carotenes are used.

Preservatives
Since the surface of cheese is an excellent medium for the development of some moulds, and an unlimited growth of moulds may seriously affect the quality of many cheese varieties, certain preservatives, such as natamycine and calcium or potassium sorbate may be used to treat the cheese rind. In some cases the packaging materials, especially those for processed cheese and for in-plastic ripened cheese, may be treated with preservatives.

Enzymes
To obtain a specific – more piquant – flavour, or to accelerate the ripening process, enzymes may be added to the milk used for the manufacture of some cheese varieties.

Further reading

See Section 9.2

9.4 Processed cheese and whey cheese

9.4.1 Processed cheese

Processed cheese is manufactured by melting one or more lots of cheese with the aid of emulsifying agents, and – if required – by adding other milk-components, such as milk fat, cream, whey and milk powder. Different varieties of cheese of different stages of ripening and cheeses that are defective in composition or quality may be used. The quality of the final product depends on the ingredients. A good processed cheese has a smooth, compact body, which is uniform in composition and colour. It is either sliceable or spreadable. The emulsifying agents (phosphates, citrates or tartrates) are added to prevent fat separation and to control the texture of the product. The spreadable product contains more water and its pH is 5.6-5.9, whereas that of the sliceable product is pH 5.4-5.6.

The constituent cheeses are ground and melted in a hot-water or steam-jacketed pan or cooker (Figure 61), together with the emulsifying salts and other components at a temperature varying between 70 and 80 °C. The lower temperatures are generally used in the production of the sliceable product, the higher temperatures in the production of the spreadable product. The cooking period, including the warming-up and cooling-down period should be short, to avoid burning or browning the product. Warming-up may be achieved by direct steam injection. After the mixture has reached the desired temperature, cooking should proceed for at least 2 to 3 minutes. Thereafter,

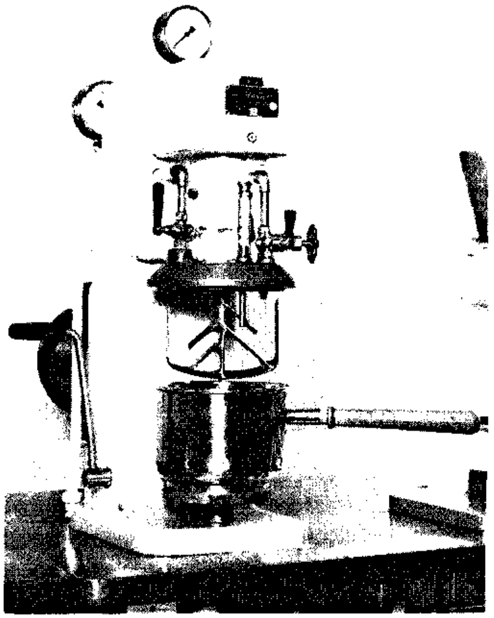

Fig. 61. Processed-cheese melting kettle. Photo: Wageningen Agricultural University.

the warm cheese paste is put directly into foil-lined containers in the case of the sliceable product and into cups or other containers in the case of the spreadable product. The contents of the melting kettle are stirred during the entire heat treatment process.

As a result of the heat treatment, the product is properly pasteurized and has an improved keeping quality, although spores will survive. There is a risk that the processed cheese will be spoiled by gas formation and blowing, as a result of the activity of germinated spores of clostridia species.

Although processed cheese can be made solely from fresh cheese, provided that the correct emulsifying salts are used, a better product will be obtained if at least 20% of the material consists of matured cheese.

9.4.2 Whey cheeses and other whey products

Whey is the by-product of cheese making. Its acidity and composition vary widely with the variety of cheese and its process of manufacture. Whey from rennet-coagulated cheeses is less acid than that of acid-coagulated cheeses. Broadly speaking, the first category has a pH above 6.0 and a titratable acidity below 15 °D, whilst the second category has a pH below 6.0 and a titratable acidity above 40 °D. In most cheese varieties, the solids content of the whey lies between 5.5 and 7.0%. As examples, the composition of whey from Gouda and cottage cheese is given in Table 17.

Since whey not only contains valuable food components but also causes serious

Table 17. Composition (%) of Gouda and cottage-cheese whey.

Component	Gouda (sweet whey)	Cottage (acid whey)
Total solids	6.85	5.60
Fat	0.35	0.05
Proteins	0.90	0.75
Lactose	4.85	3.60
Ash	0.70	0.80
Lactic acid	0.05	0.40

problems as a dairy effluent, many attempts have been made to find ways for a proper commercialization of the product. Small quantities, especially at farm level, can be used as an animal feed. The other main uses will be mentioned briefly below.

Condensed whey

The traditional process is to boil the whey in open pans until a solid product is obtained which serves as a food. Under industrial conditions, whey is condensed in evaporators under reduced pressure. The concentrated product finds a market in other food industries.

Dried whey

Whey is industrially roller- or spray-dried (Section 10.2). Dried whey is used in the food and feed industry.

Whey cheese

A number of cheeses are manufactured from whey. One group is manufactured by concentrating the whey until a solid mass that contains all the components of the whey is obtained, as in the case of Gjetost and Mysost (Norway), which are made from the whey of goat's and cow's milk, respectively. Cream may be added to obtain a smooth product.

Another group of whey cheeses is manufactured by heating acidified whey to at least 85 °C, or by boiling whey until the whey proteins have coagulated. The coagulated acid-whey proteins are collected and either pressed into cheeses and stored until they are hard, e.g. Ricotta (Italy), or they are only slightly pressed, if at all, and consumed fresh, e.g. Ricota (Brazil).

Lor cheese (Turkey) is produced by boiling the whey and salting the collected protein; the product is consumed fresh. Sometimes, large quantities of buttermilk or sour skimmed milk are added prior to boiling the whey, with the objective of commercializing the buttermilk and the skimmed milk. About 30% of full-cream milk may be added before coagulation, to improve the quality of the product.

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See also 'Further reading' Section 9.2

10 Concentrated and dried products

10.1 Concentrated milk products

10.1.1 Indigenous products

Khoa

Khoa is an indigenous type of evaporated milk. The product is typical for Pakistan and India. It is also known as khoya, khava, mava or mawa. Fresh milk is concentrated by boiling over an open fire in a shallow pan (Figure 62). The pan should be filled between 30 and 50% of its capacity. Underfilling increases the risk of burning, but high fillings make it more difficult to handle the contents. During boiling the milk is stirred continuously with a ladle with a flattened end. The moment the milk reaches a certain viscosity, the temperature must be lowered by about 20 °C to prevent scorching and burning and the development of a burnt flavour. After the contents of the pan have been heated for a long time, while being intensively stirred and worked, the product reaches the stage of 'pat-formation' (pasty consistency). At this moment the product no longer sticks to the side of the pan and can easily be collected with the

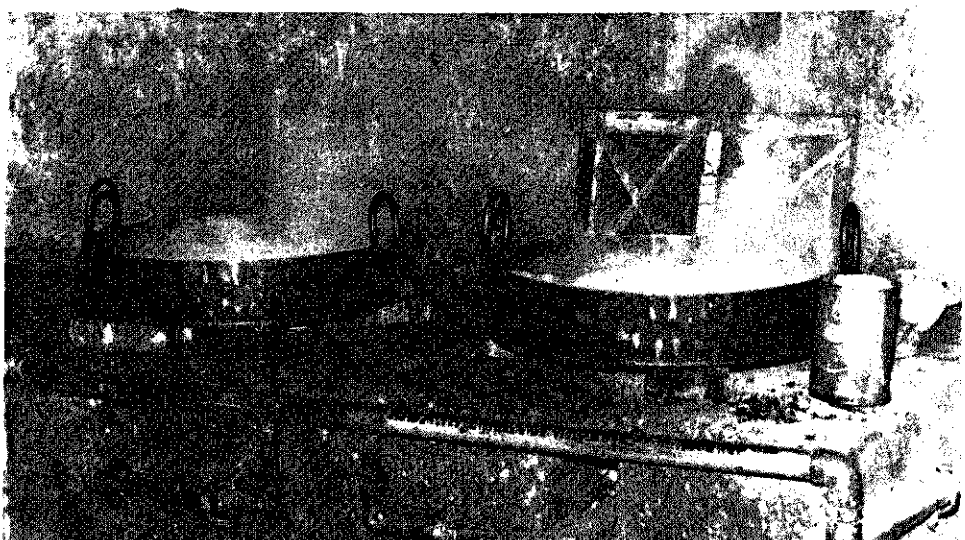

Fig. 62. Two small-capacity pans for khoa manufacture. Gas heating is used for cooking the milk. Photo: J.J. Mol.

ladle. Heating should not be continued after pat-formation, because this will easily result in the khoa having a dark colour and a burnt flavour. If it is removed from the pan too early, the product will be soft and pasty; if it is removed too late it will be hard and coarse.

The conditions of khoa production and the types of milk used vary widely, with the result that the composition and the quality of the various batches vary considerably. Nevertheless, khoa can be described as a heat-coagulated semi-dehydrated full-cream product of a soft, smooth, kneadable consistency with a slightly grainy texture. Its colour will be creamy to slightly brownish. The flavour should be 'nutty', resembling that of boiled milk. Although the original fat globules have coalesced to larger globules or droplets as a result of the prolonged heating, the product should not show any sign of 'oiling off'.

The average composition of a large number of samples of buffalo's and cow's milk khoa is given in Table 18.

The body and texture of khoa depends largely on the presence of milk fat. The minimum fat content of the milk for a high-quality product is 4% for cow's milk and 5% for buffalo's milk. Skimmed milk gives an unsatisfactory product. Milk fat makes the product less sticky during evaporation. The higher fat content of buffalo's milk may explain why khoa from buffalo's milk is less sticky than khoa from cow's milk.

Khoa produced from milk with a high acidity will have an acid flavour and a coarse structure. Neutralization of the milk before processing will improve the structure, but the flavour will remain poor.

Pathogenic bacteria and most of the other bacteria present in milk will be destroyed during the heat treatment. Improper handling and unhygienic conditions of storage and marketing cause recontamination and subsequent high bacterial counts. The presence of pathogens is not exceptional. Since khoa forms an excellent nutrient for a large variety of micro-organisms, the keeping quality is poor at room temperature. It varies from 2 to 4 days, but can be considerably extended if the khoa is stored under refrigeration. Depending on the flora, acid production or proteolytic deterioration may take place. The development of moulds and yeasts becomes visible within 3 to 6 days, accompanied by the development of a rancid flavour.

Large quantities of khoa are used for the production of sweets. An important ingredient that can be added is sugar.

Table 18. Composition (%) of khoa produced from buffalo's and cow's milk.

Component	Buffalo's milk	Cow's milk
Water	28.90	24.10
Fat	29.43	26.40
Protein	18.91	19.12
Lactose	19.73	26.23
Salts	3.39	4.15

Rabri

Rabri is another type of sweetened concentrated milk. Methods of processing differ. In Pakistan, milk is concentrated to a viscous mass in a pan on a low fire, while stirring vigorously and adding sugar from time to time. Milk that solidifies on the sides of the pan during concentration is scraped off and put back in the milk. The final product consists of a thick concentrated milk containing solidified pieces of various size. Processing procedures in India may be different. The milk is kept simmering in a wide open pan. The skins formed on the surface of the slowly evaporating milk are repeatedly removed to be kept in a cooler place, until the milk has been reduced to about 20% of its original volume. After mixing sugar through the concentrated milk, the skins are added too and mixed in. The final product will contain about 50% milk solids, 20% added sugar and 30% water.

Kheer

Kheer is produced by concentrating milk in open pans to about original one-quarter to half of the original volume, and then adding sugar (5 to 10% of the original volume). Rice may be cooked with the sugared milk, thus giving a kind of sweetened rice pudding with a high milk-solids content.

Rasagollas

Rasagollas is preferably prepared from Chhana cheese (Section 9.2) which is kneaded into small balls with a diameter of 2.0 to 2.5 cm. The balls, whose surface must be smooth and closed, are boiled for 15 to 30 minutes in a sugar syrup of about 20%. They are then put in a syrup of about 40 to 50% sugar. The product should be stored under refrigeration. The sugar content is too low to guarantee a good keeping quality at room temperature. The product may be packed in sealed tins to undergo a heat treatment with the objective of prolonging its keeping quality, but this procedure may lead to a product with a hard, rubbery texture, instead of the desired smooth texture.

10.1.2 Evaporated and condensed milks

Evaporated and condensed milk are products obtained by evaporating part of the water of milk under vacuum. The products are mainly preserved by two methods, which also determine the nature of the finished product:

– Sterilized concentrated milk (or evaporated milk, for short) which is preserved by in-package sterilization at high temperatures or aseptic packaging after UHT sterilization. The product may be packed in tins, bottles, or plastic cups.

– Sweetened concentrated milk (or condensed milk, for short) which is preserved by the addition of sugar, generally sucrose. A sugar in water concentration of at least 63.5 to 64.0% is required to suppress the development of micro-organisms. The product is generally packed in tins, but for bulk consumption it may also be packed in drums.

Both products are manufactured in the categories full-cream and skimmed. There are several standards (Table 19).

Table 19. Minimum standards for the composition of evaporated and condensed milk.

Product	Milk fat (%)			Total milk solids (%)		
	FAO/WHO	UK	USA	FAO/WHO	UK	USA
Full cream unsweetened (evaporated)	7.5	9.0	7.9	25.0	31.0	25.9
Full cream sweetened (condensed)	8.0	9.0	8.5	28.0	31.0	28.0
Skimmed unsweetened (evaporated)	-	-	-	20.0	20.0	20.0
Skimmed sweetened (condensed)	-	-	-	24.0	26.0	24.0

FAO/WHO: Food Standards Code of Principles – Codex Alimentaris. UK: Standards United Kingdom. USA: Standards United States of America.

10.1.2.1 Concentration of milk

After standardization or skimming, the milk is properly pasteurized and subsequently concentrated by boiling it under reduced pressure in an evaporator where the milk is heated by steam. This has a number of advantages over concentration under atmospheric pressure:

- the milk boils at lower temperature, resulting in less damage to its natural properties;
- concentration takes less time;
- steam-saving systems can be applied, which reduce energy costs enormously.

Evaporation plants consist of three main parts:

- the milk heater,
- the vapour separator,
- the condensor and vacuum pump.

In the milk heater the milk comes into contact with the heating surface. In the oldest types, this surface consisted of a steam jacket around the heater, that is a large cylindrical vat. In the later types, the heaters are equipped with steam-heated pipes, but plate heaters are also known. The vapours released by the boiling milk are collected in the vapour separator and discharged by a condensor, where they are brought into contact with cold water or a cold surface. The vapours condense as a result of this contact and are withdrawn by a barometric drain or a wet-vacuum pump. As a result of the continuous withdrawal of the vapours, the vacuum is maintained. Non-condensable gases, like air, which get into the evaporator, are withdrawn by pumping or other arrangements.

The original evaporators consisted of a vacuum pan whose lower part served as the milk heater and whose upper part served as the vapour separator. During concentration, milk was continuously fed into the vacuum pan to replace the evaporated water. Evaporation was terminated when the liquid in the pan had reached the required composition. At that moment the concentrated milk could be withdrawn from the installation. The system had the disadvantage of discontinuous production. This problem was overcome by the introduction of continuously operating evaporators.

In these evaporators, fresh milk is continuously fed to the plant, where it mixes with the milk already available. The moment the latter has reached the required composition, and the rate of evaporation compensates for the steady supply of water with the fresh milk in such a way that the composition of the concentrated milk no longer changes, concentrated milk can continuously be withdrawn from the evaporator. This must be done in such a way that the total supply of milk solids to the pan equals the withdrawal of solids.

The continuous system also allows for multiple-effect evaporation. Multiple-effect evaporators consist of two or more units, named effects or stages, each having its own heater and vapour separator, but with one collective condensor for all units. Each successive unit operates at a lower temperature; that means that in each successive unit the milk boils at a lower pressure and consequently at a lower temperature. The milk is continuously introduced into the first heater, where it is partly concentrated. The partly concentrated milk is then led to the second heater, and so on. The vapours of the boiling milk in the first heater are collected in the first vapour separator and can be used to heat the partly concentrated milk in the second heater, because the temperature of these vapours is higher than that of the boiling milk in the second heater.

This system allows for a considerable economy in steam consumption. Theoretically, 1 kg of steam is required to evaporate 1 kg of water in a single-stage evaporator. Since in a two-stage evaporator for every kg of water that is evaporated by live steam 1 kg of vapour will become available, which can be used to evaporate another kg of water, steam consumption will be half that of a single-stage evaporator. The actual steam consumption is always slightly higher than the theoretical one, because of heat losses.

The type of evaporator discussed has a number of disadvantages, such as:

– The installation contains a large quantity of milk, to which only small quantities of fresh milk are fed continuously, and from which only small quantities of concentrated milk are withdrawn. This means that the milk has a long residence time in the plant;

– The system is not very suitable for extension of te number of stages beyond two, which would have meant still lower steam consumptions.

Therefore, new types of evaporator have been introduced, namely the falling- and climbing-film evaporators. A single-stage falling-film evaporator is depicted and described in Figure 63 and a four-stage falling-film evaporator in Figure 64. The milk heaters of these evaporators are characterized by the fact that the comparatively long tubes are not filled with milk, but that a film of milk moves at high speed along the inner surface of the tubes, thus allowing for an instantaneous heating of the milk and an easy evaporation of the water. After the milk has passed through the tubes and has collected in the vapour separator, it is pumped directly to the next stage of the installation. This type of evaporator contains only a small quantity of milk, and the milk has a very short residence time in these plants.

All evaporating plants are equipped with a compressor (usually, a thermocompressor) in which vapours from the first stage are mixed and compressed with live steam. As a result of this mixing, the temperature of the vapours is increased to such an extent that they can be used for heating the milk in the same stage (i.e. the first stage). The remainder of the vapours are introduced into the heater of the second unit, which has a lower evaporating capacity than the first stage. The use of a thermo-compressor effects a further saving of steam. The operation of a thermo-compressor in a one-stage evaporator is explained in Figure 63.

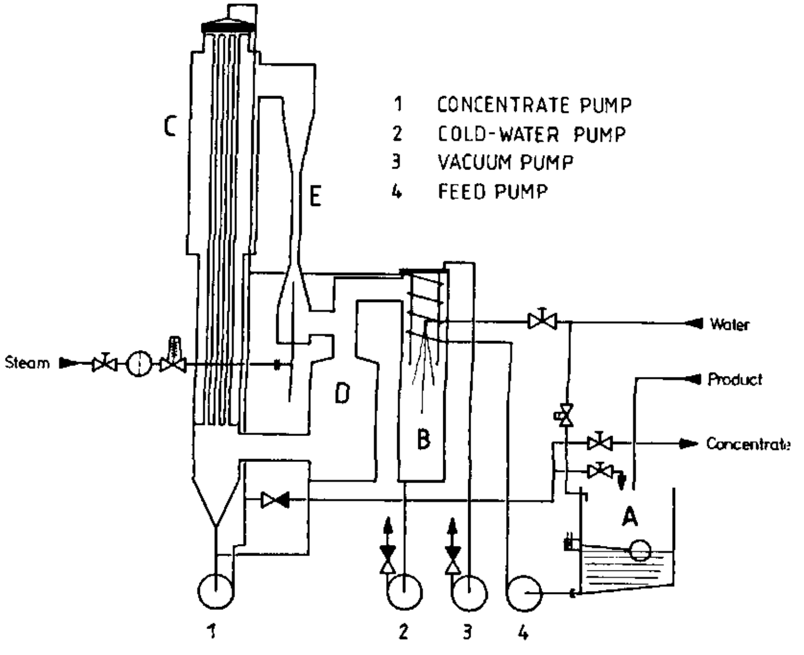

Fig. 63. Flow diagram of compact falling film evaporator. Single-stage evaporators are available especially for low capacities. Milk is pumped (4) from a balance tank (A) through a condensor (B) (where the milk is preheated by vapours) to the top of the evaporator (C). Here it is distributed as a thin film over the inner surface of the vertical pipes in the steam chest (the so-called calandrium). The milk is heated by recompresssed vapour from the outside of the tubes, which causes water to evaporate from the milk inside the tubes. The mixture of concentrated milk and evaporated water leaves the pipes at the bottom of the calandrium. The concentrate is discharged by a pump (1), whilst the vapour is led to the cyclone vapour separator (D), where concentrate carried along with the vapour is separated at high centrifugal velocities and is led to the concentrate pump (1). The vapour is partly condensed in the condensor in contact with cold water (pump 2), and partly compressed and mixed by the injection of live steam in a thermo-compressor (E). The recompressed vapour has a higher temperature than the milk, and – consequently – it is used to heat the milk in the calandrium. In multi-stage evaporators, part of the vapour is led to the second stage instead of to the condensor (see also Fig. 64). The action of the condensor and the thermo-compressor create a vacuum in the evaporator by sucking the vapours from the evaporator away. A vacuum pump (3) is required to remove non-condensable gases. Courtesy: APV Anhydro AS.

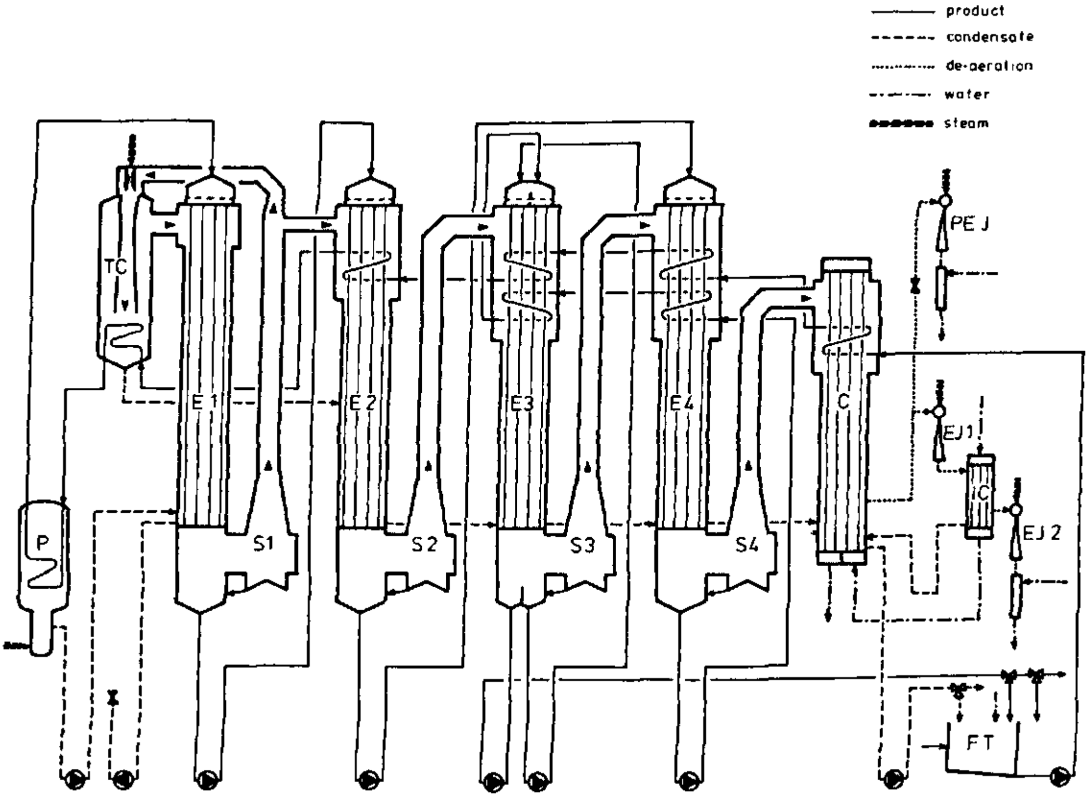

Fig. 64. Flow diagram of multi-stage falling-film evaporator. The installation consists of four evaporators (tubular heat exchangers) (E_1 - E_4) with cyclone vapour separators (S_1 - S_4), a tubular surface condensor (C), a two-stage ejector (EJ_1 and EJ_2), with an intermediate condensor (IC) for the removal of non-condensable gases, a pasteurizer (P), a thermo-compressor built into a coil preheater (TC), a feed tank for fresh milk (FT) and another ejector (PEJ). Milk from the balance tank is pumped through the coil preheaters built in the calandria of C, E_4, E_3 and E_2, and in the thermo-compressor (TC) and the pasteurizer (P), to the top of the first evaporator (E_1). Here it is distributed as a thin liquid film over the inside of the pipes of the calandrium, where water is evaporated from the milk. The partly concentrated milk is collected at the bottom of the evaporator and pumped to the top of the second evaporator (E_2). Droplets carried along with the vapour are separated from it in the cyclone S_1. The vapour will partly be fed to the second calandrium (in E_2) for heating the partly concentrated milk in its pipes. The other part of the vapour coming from the first evaporator is mixed and compressed by live steam in the thermo-compressor (TC) to be applied for heating the milk film in the pipes of the first calandrium (see also Fig. 63). The partly concentrated milk from the second evaporator will be fed to the third one (E_3) and from there to the fourth one (E_4), where it reaches its final concentration. Vapour produced in the pipes of the second calandrium will be used for heating in the third calandrium, and the vapours of the third one for heating in the fourth one. The vapours of this last stage will ultimately be condensed in the condensor (C). The flow of vapours through the installation is possible, because each successive evaporator has a lower vacuum than the previous one. Vapours fed into the calandria give up their heat by condensation; the condensates are discharged from the bottom of the calandria, as is the mixture of vapour and cooling water from the condensor. Courtesy: H.J. Scheffers B.V.

10.1.2.2 Evaporated milk

After concentration, the product will be homogenized (e.g. 220 and 50 atm at 65 °C) to obtain a stable dispersion of the fat. Homogenization must not be too intensive, because it detrimentally affects heat stability. The concentrated milk is cooled and packed in tins or glass bottles, which are sterilized in batch or in continuous operating sterilizers for about 20 minutes. Revolving sterilizers are required to keep the cans moving, thereby preventing the product from burning, and ensuring that the heat is transferred quickly and evenly throughout the product. The evaporated milk must be heated to its sterilizing point (110 to 120 °C) as quickly as possible, and after sterilization it must be cooled as quickly as possible. The product should be stored at a cool place. One week after production, the product may be checked for quality and be released to the market.

Defects

Non-sterility of evaporated milk may be the result of leaky tins or of insufficient sterilization. When non-sterility is the result of an insufficient heat treatment, thermoduric and heat-resistant spore-forming bacteria wil have survived. Sweet coagulation is often caused by *Bacillus subtilis*, whereas *Bacillus coagulans* may be responsible for sour coagulation. Some spore-formers, like *Plectridium foetidum*, may withstand 15 minutes sterilization at 115 to 120 °C. The most heat-resistant, however, are the spores of *Bacillus stearothermophilus* var. *calidolactis*. They may develop under tropical conditions and spoil the tins of evaporated milk (see also Section 6.5). The bacteria are able to grow in the evaporators and balance tanks where milk is stored at higher temperatures (e.g. even at temperatures higher than 45 °C). This must be avoided.

Lipases and proteases of bacterial origin (psychrotrophic bacteria) may not be completely inactivated during sterilization. For this reason, and to minimize the presence of heat-resistant spores as much as possible, the bacteriological quality of the fresh milk may not be disregarded in favour of placing entire reliance on the sterilization process.

Evaporated milk should have a certain viscosity to show its richness and to prevent creaming. The greatest increase in viscosity is caused by sterilization. Milk with a low heat-stability may result in a grainy product, or even coagulation during sterilization. The factors that control the heat stability of evaporated milk during sterilization are rather complicated. It is believed that the high concentration of milk salts plays a part in destabilization, as does the lowering of the pH resulting from preheating and concentration of the milk. Nevertheless, intensive preheating (e.g. 30 seconds at 120 to 130 °C) is an important way of improving stability, but adding a stabilizing salt, usually disodium phosphate, will help increase the pH of the concentrated product and promote stability. Since the heat stability of different consignments of milk may vary widely, it is advisable to make test sterilizations using small quantities of the concentrated product to which different quantities of the salt are added. The salt is added as a watery solution, which at the same time can be used to standardize the product to the required composition. Therefore, the milk must be slightly 'over-concentrated' in the evaporator.

As a rule, evaporated milk tends to become thinner during storage, but sometimes the viscosity of the product increases suddenly during prolonged storage, which even may lead to gel formation. Products with a high solids content are especially susceptible to age-thickening. Changes in viscosity are strongly accelerated by high storage temperatures. The causes of this phenomenon are not fully understood. There seems to be no relation between age-thickening and heat stability. Measures taken during processing may adversely influence these phenomena.

Creaming may occur as a result of inefficient homogenization, especially if the product has a low viscosity.

UHT sterilization

An alternative to prolonged sterilization after packaging is UHT sterilization (e.g. 15 seconds at 140 °C) followed by aseptic packaging. Milk should be UHT-preheated as explained before, to prevent heat coagulation during sterilization. If it is necessary to add a stabilizing salt, this should be done before sterilization; homogenization (e.g. 450 atm at 60 °C) should take place immediately after sterilization. The whole manufacturing process should be implemented in one run. Even if the product is cooled during periods that the process is interrupted, the risk of age-thickening is increased. Double UHT treatment (presterilization and post-sterilization) gives the product such an intensive heat treatment that all bacterial spores are killed and all enzymes are inactivated; this is not always so in the case of UHT presterilization followed by traditional in-can sterilization.

10.1.2.3 Condensed milk

Milk for the manufacture of condensed milk should be homogenized before evaporation starts, to prevent the non-skimmed product from creaming; this is especially important if a product with a comparatively low viscosity is being made. A low pressure (e.g. 50 atm) is used, because homogenization increases product viscosity. Contrary to evaporated milk, the concentrated product is not heat-treated. Therefore, before evaporation starts, pathogenic bacteria and deleterious micro-organisms should be killed and milk enzymes must be inactivated, for instance by UHT treatment.

Condensed milk is solely preserved as a result of its high sugar content. The sugar may be added at various stages of the production process, i.e. before, during or at the end of the evaporation process. Sucrose (cane or beet sugar) as well as dextrose (glucose) is used, although it is believed that the latter makes the product more susceptible to brown discolouration (Maillard reaction).

After concentration, the condensed milk should be cooled as quickly as possible. Since the lactose solution in the product is supersaturated, crystallization is unavoidable. Special care must be taken to avoid the formation of large lactose crystals, which cause the defect of sandiness. Such crystals tend to form when only a few crystallization nuclei are available: these nuclei are able to grow slowly and steadily if the warm product cools slowly. As many as 400 million crystals per ml should be formed to obtain a smooth product. This is achieved by seeding the product with fine lactose crystals which initiate the crystallization process, in combination with special cooling techniques. A common procedure consists of rapidly cooling the condensed milk to about 30 °C after it has left the evaporator. At this temperature it is seeded with lactose and the product is vigorously agitated whilst cooling continues. After cooling it is still possible to standardize the solids content of the product by adding water, but it may be difficult to distribute the water evenly through the viscous product. Uneven distribution means that the parts of the product with a low sugar concentration will be susceptible to deterioration.

Condensed milk is packed in tins or in large-capacity containers, which should be completely filled to exclude air.

Defects

Since no further heat treatment takes place after the milk has been pasteurized, the strictest possible hygiene should be observed, to limit recontamination. The high sugar content and the absence of air (oxygen) must protect the product against the development of micro-organisms. If these conditions are not fulfilled, gas-producing yeasts of the genus *Torulopsis,* or moulds belonging to the genus *Aspergillus,* may develop. Gas formation may be serious enough to bulge the tins, which may even burst open along the seams. The development of moulds may lead to so-called 'buttons' consisting of mould colonies and coagulated milk to form in the product. A number of other micro-organisms may develop and cause bacteriological thickening of the contents of the tins. Enzymes produced by psychrotrophic bacteria in the original milk will survive the production process and may cause defects.

Sandiness is caused by the presence of large lactose crystals, but sucrose crystals may also be found if the fraction of water plus sucrose contains more than 64.5% sucrose.

A serious defect in condensed milk is age-thickening, which gradually increases the viscosity until a jelly-like product is formed. The occurrence of the defect depends on the properties of the original milk, but the risk can be reduced by preheating the milk (for a few seconds at 130 to 140 °C) and by adding the sugar at a late stage of the evaporation process. The risk of the defect increases concomitantly with solids content and the storage temperature of the condensed milk.

Another defect is the development of a brown colour if the product is stored at higher temperatures, i.e. at temperatures of 30 °C and higher. Below 20 °C there will be little or no discolouration.

Further reading

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10.2 Dried products

10.2.1 Milk powder

Milk powder is a product obtained by the removal of water from milk, partly skimmed milk or skimmed milk (definition Code of Principles FAO/WHO). The compositional quality factors are set out in Table 20.

Milk powder with a fat-content above 40.0% is often referred to as cream powder.

The two principal processes for the manufacture of milk powder are the roller or the drum process and the spray process. Other systems are the foam-mat process and the freeze-drying process. More recently, equipment in which combinations of these fundamental processes are found has been developed.

10.2.1.1 Roller or drum drying

In this system, milk is dried on the surface of a rotating horizontal drum. The milk is spread in a thin film on the surface of the drum and dried in one rotation. The dried film is removed by one or more scraper knives. The drum is suspended from a heavy frame and consists of a steel cylinder that is internally heated by steam, for which it is provided with a steam inlet valve and a condensate discharge device. After it has been removed from the drum, the film of dried milk is pulverized.

There are several roller systems.

Table 20. Composition (%) of various categories of milk powder.

Product	Milk fat content	Water content (max.)
Whole milk powder[1]	min. 26.0, less than 40.0	5
Partly skimmed milk powder	more than 1.5, less than 26.0	5
Skimmed milk powder	max. 1.5	5

[1] Often designated as full-cream milk powder.

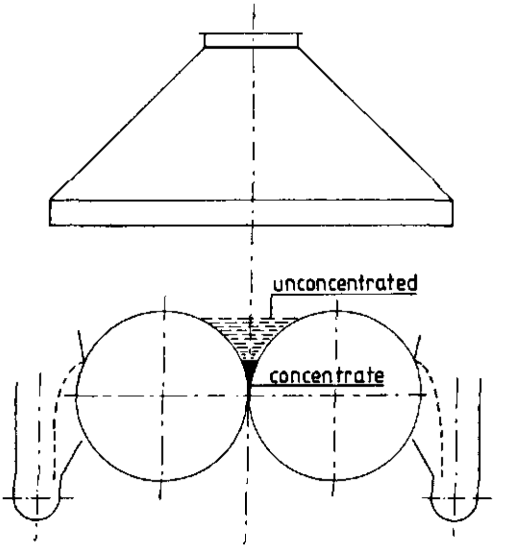

Fig. 65. Double-drum dryer. Courtesy: Goudsche Machinefabriek B.V.

Double-drum dryer

Double-drum dryers have two cylinders that rotate in opposite directions. The size of the cylinders varies in proportion to the capacity of the dryer, but is limited by constructional requirements; the length generally varies between 1 and 3.5 m and the diameter may vary from 0.5 to 1.5 m. When drying non-concentrated milk or whey, a continuous supply of milk is equally divided over the total length of the trough that is formed between the two cylinders (Figure 65). Some of the milk, boiling vigorously in the trough, flows continuously through the narrow opening between the two cylinders. It adheres to the surface of the drums, where it dries in about three-quarters of a revolution, before being scraped off the drum by a knife. The speed of rotation depends mainly on the pressure of the steam: low pressures correspond with slow rotation speeds. The film must be exposed to the hot surface of the drums long enough to dry completely, but not too long in case it burns. Double-drum dryers may have rotation speeds of 15 to 18 rpm and steam pressures of 7 to 10 atm.

While it is boiling in the trough, some of the water in the milk evaporates and the solids content of the milk increases until the moment it passes the slit between the cylinders. On the surface of the drum, the milk is exposed to the high temperature of the drum, but as a result of the evaporating water the temperature of the film remains comparatively low, but increases rapidly when it reaches the scraper knife, however, it does not exceed 90-100 °C.

The solubility of this type of milk powder is low, mainly because of the intensive heat treatment of the milk in the trough. Roller-dried milk powders of this type are not suitable for the manufacture of most reconstituted or recombined milk or milk products, but they are used in the food industry; the skimmed product is used in the animal feed industry.

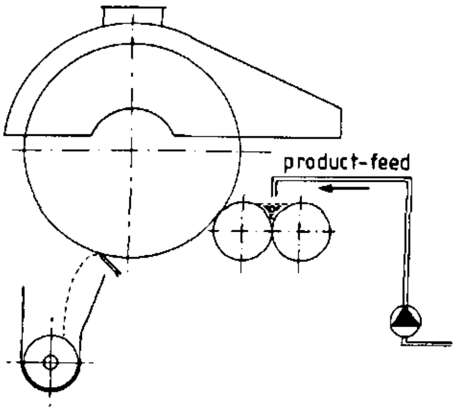

Fig. 66. Single-drum dryer. Courtesy: Goudsche Machinefabriek B.V.

This type of drying has the advantage of comparatively low initial costs of investment and simple operation. It is suitable for low capacities of between 500 and 1500 l milk per hour. The double-drum dryer is less suitable for processing preconcentrated milk, mainly because of the intensive heating and because the milk becomes more concentrated in the trough between the two cylinders.

Drum dryers for preconcentrated milk

To avoid the heat treatment in the trough of the double-drum dryer adversely affecting the quality of the product, two systems have been developed, both working with a feed of preconcentrated milk (or whey) with a solids content of 40 to 45%. In these cases the milk is preconcentrated in an evaporator and by means of two rollers is fed to the surface of the drying drum (Figure 66). The roller in contact with the drum carries the milk along its surface and transmits it to the drying drum in an accurately controlled layer.

The second system does make use of a double-drum dryer, but feeds a minimum quantity of concentrate between the drums so that the concentrate does not start to boil; it is spread on the drum surface immediately.

The steam pressure in the drums of these dryers is generally low, e.g. 2 to 3 atm, and the drying time is very short because of the rapid rotation speeds (up to 30 rpm). This procedure ensures that high capacity is combined with an improved solubility of the powder. It is claimed that solubility figures as high as 97% can be reached for high-quality powder. Powders manufactured by feeding unconcentrated milk on double-drum dryers are less soluble (less than 90% solubility).

Vacuum roller dryers

By enclosing roller dryers in a chamber from which the air and vapours are withdrawn, drying at much lower temperatures than used for atmospheric dryers is possible, thus allowing for the manufacture of products with a much better solubility.

Roller powder consists of small flakes of dried milk, the fineness depending on the grinding procedure. The fat dispersion is almost completely destabilized.

Staleness is the principal defect that develops during storage, even if the moisture content of the powder is low.

10.2.1.2 Spray drying

In this process a mist of small milk droplets is sprayed into a stream of hot air that is forced through a suitably designed drying chamber (Figure 67). During the time the air stream passes through the chamber, the milk droplets are dried by exposure to a stream of hot air. The rapid evaporation of the water in the milk droplets guarantees a low drying temperature, even though the product is in direct contact with the hot air. Only at the end of the drying process, when only a little water is left in the droplets, does the temperature sometimes rise. For this reason, the powder must be removed from the air as quickly as possible after the drying process has been completed. Prolonged exposure of the dry product to hot air is detrimental to its quality. The air enters the drying chamber at temperatures that may vary from about 160 to 250 °C – depending on the process – and leaves the chamber at temperatures of 90 to 120 °C. The milk powder is removed from the air by means of filter bags or separation cyclones.

The hot drying air is generally produced in indirect, gas- or oil-fired heaters or in steam heaters but, direct electrical or gas-fired heaters are used as well.

To disperse the milk as small droplets in the hot air stream, it is whirled from a rapidly spinning disc or is pumped under high pressure through a spray nozzle.

Before drying, milk is preconcentrated to 45-50% solids content. Preconcentration is applied because:

- far less energy is required to evaporate water in an evaporating plant than in a spray chamber;
- the bulk density of the product will be higher and the air content of the powder will be lower if the milk is preconcentrated;
- the use of preconcentrated milk enables a smaller spray dryer to reach the same capacity in terms of milk used.

The original system of spray drying – as described above – is known as the one-stage drying. More recently, a two-stage drying system has been developed, which produces powder with better free-flowing properties. In this system, the powder is discharged from the drying chamber (C in Fig. 67) just before it is completely dry (e.g. at a moisture content of 5-6%) into a fluid-bed[1] dryer and cooler (E in Fig. 67). This dryer consists of a vibrating perforated stainless steel plate, through which first low-

[1] Fluidization is the result of a gas flowing through a distribution plate, e.g. a perforated stainless steel plate. As a result of the gas which is blown through it, a product (in this case milk powder) on top of the plate behaves like a fluid, which can flow from the side where it is fed to the system (the fluid bed), to the side where it is discharged. Depending on the temperature of the gas, the product can be warmed and dried, or cooled.

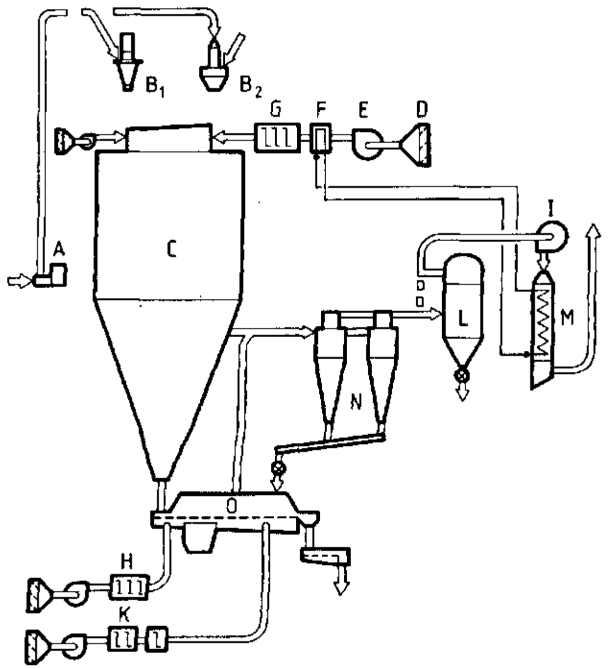

Fig. 67. Spray dryer. Concentrated milk is pumped from a balance tank (A) to a spinning-disc atomizer (B_1) or a nozzle atomizer (B_2), which distribute the product into fine droplets in the drying chamber (C). The droplets are dried by air blown into the drying chamber by a blower (E) after being filtered (D), preheated (F) and heated (G). The almost dry powder falls on the belt of the fluid-bed dryer (O), where it is first heated by hot air (blower H) and thereafter cooled by cold air (blower K), before it is discharged. Very fine milk-powder particles carried along with the drying air and cooling air are recovered in cyclones (N), where air and powder are separated by centrifugal force. Particles that escape separation in the cyclones may be recovered in a filter bag (L). Before discharge to the atmosphere, the clean air may be blown through a heat exchanger (M) for heat recovery by a liquid, which preheats the incoming drying air (F). Courtesy: NIRO Atomizer SA.

temperature drying air and then cooling air are blown. During the time the powder 'flows' over the fluid bed from the side of the inlet to the side of the outlet, it is dried completely and cooled. Since the powder leaves the drying chamber at a fairly high moisture content, the outlet temperature of the air will be low, which guarantees that the dryer operates with a high thermal efficiency.

The latest dryers are three-stage. They have an additional fluid bed in the conical part of the drying chamber.

10.2.1.3 Freeze drying

Freeze drying is a process in which deep-frozen (−25 to −40 °C), preferably concentrated, milk is dried under a very high vacuum. At these temperatures the ice in the frozen milk sublimates, i.e. it evaporates without passing through the water phase. Since the drying temperature is very low, the chemical properties of the product will not change. This phenomenon can only be fully exploited if the product has not been intensively heat-treated before freeze drying, in other words: pasteurization should be modest if full benefit is to be obtained from the characteristics of the process. The milk should be concentrated at the lowest possible temperature.

The process is too expensive for the production of ordinary dried milk.

The product is porous. Its keeping quality is poor because of rapid oxidation of the milk fat.

10.2.2 Properties and quality of milk powder

In the previous sections, some remarks were made about the quality and properties of roller-dried and freeze-dried milk powder. As spray drying is by far the most important system for the manufacture of milk powder, properties and quality of spray-dried milk powder will be discussed in detail here.

Properties of spray-dried milk powder

Spray powder consists of small 'rounded' particles, most of which include one or more vacuoles of air. Unlike roller-powder, the fat dispersion in the product is practically intact. The lactose in spray-dried milk powder is in a very hygroscopic amorphous state and easily attracts moisture from the atmosphere; as a result, the lactose tends to crystallize and the powder will cake. Roller-dried powder is far less likely to cake.

Whenever ordinary spray powder is dissolved in water, lumps that are difficult to disperse are formed. This can easily be explained. The openings or pores between the individual particles of milk powder are very narrow, making it difficult for water to penetrate between these particles. Instead, lumps of powder that form as a result of the poor free-flowing characteristics of the powder are wetted on the outside if they come into contact with water. The very hygroscopic lactose on the outside of these lumps will absorb water immediately, thus forming a viscous layer of highly concentrated lactose, which almost completely protects the enclosed powder against contact with the water, thus interfering with a quick reconstitution of the powder.

Various attempts have been made to facilitate the reconstitution of milk powder, in other words to produce a milk powder that dissolves very quickly, without affecting its solubility as such. Almost all the techniques are based on improving the penetration of water into the powder. This is achieved by producing light agglomerates of individual particles separated by wide pores. There are two systems for the production of such instant powders:

- the one-way or straight-through process,
- the rewetting process.

In the one-way process, the milk powder is taken from the drying chamber when it is not yet completely dry, and transferred to a fluid-bed instantizer. Here it can ag-

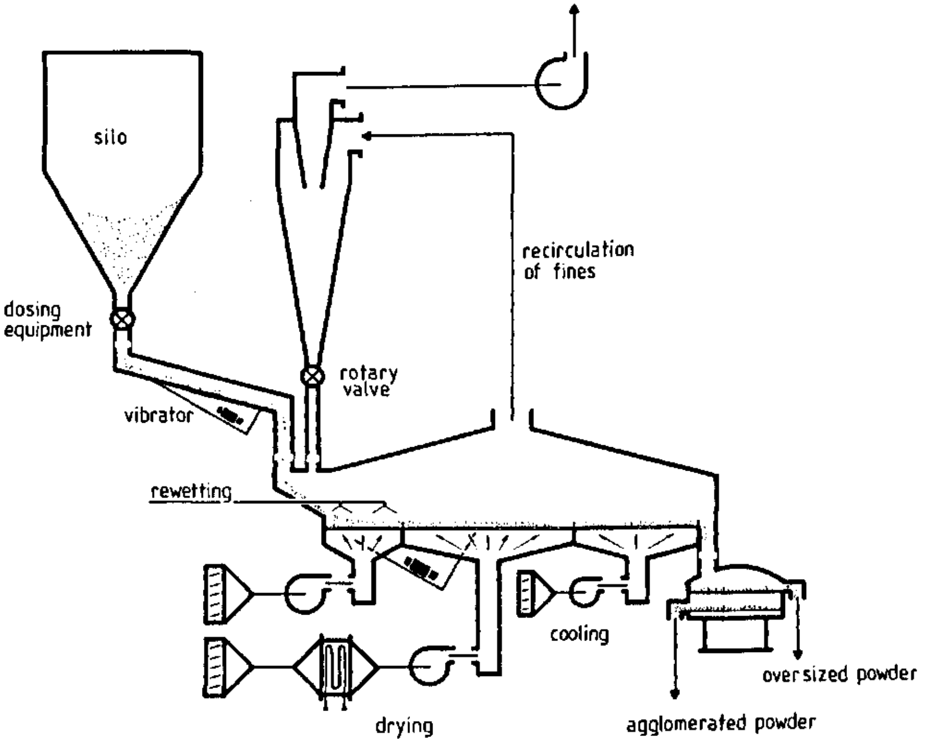

Fig. 68. Fluid-bed instantizer. Courtesy: Schiedamse Werktuigen & Machinefabriek B.V./APV Anhydro AS.

glomerate and dry completely, after which it is finally cooled. The principle of this procedure and the equipment is similar to that of the two-stage spray drying process and, not surprisingly, the powder manufactured by this process has improved instant properties.

In the rewetting process, milk powder is rewetted on a fluid-bed instantizer to make it sticky again; this results in the desired agglomeration of the powder (Figure 68). Thereafter, it is dried again and cooled. This process of instantizing can be performed in plants where no spray dryers are available.

The processes described for the production of instant milk powders can only be successfully applied when using skimmed milk powder. In full-cream milk powder and partly skimmed milk powder the presence of the water-repellent milk fat hampers the wettability of the product. This hampering can be overcome by coating the powder particles with a very thin layer of lecithine. This can be achieved by spraying a lecithine mix through a nozzle system on the milk powder particles on the fluid bed of a two-stage spray dryer or an instantizer.

Milk powder with improved dissolving properties, such as instant powders, generally also show better free-flowing properties.

Quality of spray-dried milk powder

Generally, spray-dried milk powder undergoes a moderate heat treatment in the drying chamber, unless it remains in the chamber for too long a period after the powder particles are sufficiently dry. The heat treatment the product undergoes before it enters the drying chamber, namely the time and temperature of milk pasteurization and – to a lesser extent – of milk concentration, plus the time and temperature of the storage of the concentrated product before drying, are of much more influence on the properties of the powder.

Spray powders are classified into three categories, according to the intensity of heat treatment:
- low-heat milk powder,
- medium-heat milk powder,
- high-heat milk powder.

Low-heat milk powder. This powder is characterized by negligible changes in the natural properties of its components. After reconstitution or recombining, the milk shows the same properties as milk that has been pasteurized for a short period at a low temperature. This is achieved by using production methods that expose the milk to the lowest possible temperature for the shortest possible periods of time during powder making. HTST pasteurization should be applied at a time-temperature combination no higher than is absolutely necessary to guarantee the killing of all pathogenic and most other deleterious bacteria and the inactivation of harmful enzymes. Since no high temperatures are applied, only milk of sufficiently high quality and with a low plate count should be used for the manufacture of this type of powder.

Medium-heat milk powder. Most of the normal industrial powders belong to this category. Pasteurization may be intensive, e.g. a few minutes at temperatures of 85 to 125 °C. The milk may be introduced into the evaporator at pasteurization temperature. Sometimes, the concentrated milk is heated again to about 70 °C immediately before drying; this lowers the viscosity and allows for spraying into finer droplets. This increases the capacity of the spray-dryer. High-temperature drying can be applied.

High-heat milk powder. For the production of this type of powder the milk has to undergo a severe heat treatment. Pasteurization can be particularly intensive: the time-temperature combinations may vary from 30 minutes at 80 °C to a few minutes at 140 °C.

The intensity of the heat treatment of the milk during processing determines the quantity of whey proteins that are still soluble in the powder. When classifying spray-dried milk powder, the American Dry Milk Institute (ADMI) uses the expression 'Whey Protein Nitrogen' (WPN) index, to indicate the quantity of soluble whey proteins in mg still available in 1 g of milk powder. The WPN index for the three categories is:

- low-heat milk powder: equal to or more than 6.9 mg/g
- medium-heat milk powder: 1.51 to 5.99 mg/g
- high-heat milk powder: less than or equal to 1.5 mg/g.

Since bacterial lipases and proteinases are generally not inactivated in most processes of milk powder production, these enzymes, together with bacterial spores, may be found in the powder, with all the consequences for the quality of the recombined products, such as recombined UHT milk (Section 6.5).

Milk powder must be packaged in materials that are impermeable to moisture and odours. Tins or drums may be used, but these are too expensive for bulk packaging. Multi-walled paper bags with a polyethylene inner bag for protection against moisture and odour are cheaper and easier to handle and stack. The plastic must be odourless and may not contain components that can be absorbed by milk powder. The bags must be hermetically sealed, preferably by heat sealing or by 'double knotting'. The powder should be stored in a cool and dry place to prevent chemical deterioration. Although high-quality skimmed milk powder has an excellent storage life, it is not good practice to maintain large stocks; especially not under conditions of high ambient temperatures.

Low, medium and even high-heat milk powders can have an excellent solubility. Poor solubility is caused by a too intensive heat treatment, especially of the concentrated milk, and prolonged exposure of the milk powder to high temperatures. As mentioned earlier, it is very important to remove the milk powder from the drying chamber as quickly as possible after drying and to cool it.

Spray powder that has a high moisture content – either because it has been insufficiently dried or because it has absorbed water during storage – will deteriorate easily (Section 5.4). The solubility will decrease, the colour will darken and an unpleasant stale flavour will develop as a result of insoluble compounds, being formed by a reaction between the proteins (or their denaturation products) and the lactose (Maillard reaction). Drying to a water content below 4% – preferably to 3% – and packaging the milk powder in moisture-impermeable materials is very important for protection against Maillard reactions.

Spray powders containing milk fat will easily show defects caused by the oxidation of the fat, resulting in the development of a tallowy off-flavour. Powders can be protected against oxidation by gas packing, i.e. by replacing the air in the package (which must be impermeable for oxygen) by nitrogen. Gas packing is a normal procedure for the retail packaging of all milk powders containing milk fat. Gas packing is difficult to implement for wholesale packages. Therefore, the solids-non-fat (skimmed milk powder) and the milk fat (anhydrous milk fat) are packed, stored and shipped separately. They may be recombined in the production of full-cream or standardized milk and milk products (Section 5.4).

10.2.3 Whey powder and buttermilk powder

Whey powder

Spray drying of whey gives rise to a few problems. Whey must be concentrated before spray drying, because the drying of unconcentrated whey will result in an extremely fluffy product, which requires large volume packaging materials. In modern evaporators, it is not too difficult to concentrate whey to a solids content of 45 and even 60%, provided the whey is sweet and acid production has not taken place or is negligible. Since the solids content of whey is much lower than that of milk, the capacity of the evaporator must be larger to feed the same capacity drying chamber.

The lactose content of the whey solids is very high – about 70% – which makes the product difficult to dry. Therefore, the air leaving the dryer should be warmer than in the case of the manufacture of milk powder and the powder must be transported and cooled by air of a rather low relative humidity.

Whey powder is very hygroscopic as a result of its high lactose content, and its free-flowing properties are very poor. It is possible to produce so-called non-hygroscopic whey powder (in which most of the lactose is crystallized) by cooling the preconcentrated product to, for instance, 20 °C and allowing the supersaturated lactose to crystallize before drying. Crystallization is initiated by seeding the concentrate with lactose crystals. After drying, about 70% of the lactose consists of non-hygroscopic crystals.

Buttermilk powder

Sour-cream buttermilk can only be preconcentrated to about 30% solids content, because the concentrated product is very viscous. Since both the buttermilk and the concentrated buttermilk have a low solids content, sour-cream buttermilk powder can only be produced in equipment with a low capacity. Moreover, residues are quickly deposited in the equipment (especially in the evaporator), which necessitates interruptions to the process for cleaning. Consequently, production costs are high.

The product has a low keeping quality and is liable to cake. If the sour-cream buttermilk is neutralized before drying, concentration and drying will be facilitated, but the product will be of lower quality than sweet-cream buttermilk powder. The latter can be obtained by drying sweet-cream buttermilk. This product – although very prone to caking and very sensitive to oxidation – has many excellent applications in the food industry.

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11 Cream, flavoured milk and edible ices

11.1 Cream

Market cream, i.e. cream intended for direct human consumption, is produced in a variety of different fat contents and under various names, subject to governmental legislation. The most important cream products are:

- light cream, usually sterilized, with a fat content of about 20%;
- whipping cream, usually pasteurized, with a fat content between 35 and 40%;
- cultured cream with a fat content of about 20%, fermented with lactic acid bacteria.

The cream used for these products must be obtained by creaming fresh milk of excellent quality. Because of their high fat content, the products are especially susceptible to defects of the fat. Small quantities of cream can be pasteurized by putting the container of cream in a hot water bath and keeping it there at a temperature of 80 to 85 °C for about 10 minutes, while stirring. Thereafter, the cream should be cooled quickly to the lowest possible temperature.

Sterilized light cream

The main problems encountered in the manufacture of this product are the creaming and coalescence of the milk fat globules, and heat destabilization. The answer to creaming is homogenization, but this results in an enormous increase in the number of fat globules and consequently in the total surface area of the fat. This surface will adsorb large amounts of new membrane material, primarily consisting of casein. The many small fat globules with their adsorbed casein behave like casein micella, thus decreasing the heat stability of the product.

The heat stability can be improved by adding citrates or phosphates, but best results are achieved by minimizing the intensity of homogenization as much as possible, e.g. by practising a two-stage treatment at 120 and 35 atm at a temperature of about 70 °C. After homogenization and packaging in bottles or tins, the cream is sterilized at a temperature of 115 to 120 °C for 15 to 20 minutes.

Half-and-half cream

The fat content of half-and-half cream may vary, but usually it is no lower than 10%. It is mainly used as a coffee whitener, and as such it competes with light cream. A few per cent skimmed milk powder may be added to increase the whitening capacity; simultaneously, the risk of feathering is decreased. The product is either batch or HTST pasteurized, or in-package UHT-sterilized. Homogenization takes place at a pressure of about 100 atm. An alternative to in-package sterilization is UHT sterilization, followed by aseptic packaging in one-way packing materials (e.g. cartons, plastic cups).

A major defect of light cream is the *formation of feathery floccules* after it has been added to hot coffee. The causes of feathering are similar to those of heat instability; to avoid this defect, particularly high homogenization pressures should be avoided. The quality of the coffee and the water with wich it is made also play a part; acid coffee and hard water promote feathering.

Pasteurized whipping cream

The manufacture of whipping cream should be directed to producing a product that is guaranteed to have excellent whipping properties. In other words, *the cream must be capable of being whipped into a stable and stiff, bulky product within a reasonable period of time.* The cream is usually intensively pasteurized in batch, e.g. at a *temperature of 85 °C for at least 10 minutes,* and packaged in bottles or in one-way packages after cooling to 5 °C. Sometimes, pasteurization takes place after packaging. Usually, *the product is not homogenized,* because this adversely affects the whipping properties. *Ripening the product for 24 hours at 5 °C to ensure that as much as possible of the fat has solidified,* improves the whipping characteristics.

Cultured cream

Cultured or sour cream is manufactured by fermentation of cream, usually with a fat content of about *20%, with 1 to 3% of a lactic acid starter, e.g. a butter starter at 20 °C,* until the acidity of the cream is about 75 to 85 °D. Before fermentation, the cream is pasteurized at 75 to 85 °C for 30 minutes, and after cooling to 45 to 65 °C it is homogenized at a pressure that may vary from 125 to 200 atm. To improve the body of the product, a small amount (0.25-0.50%) of a stabilizer, such as gelatin or sodium alginate, may be added. Sometimes, up to 2% of skimmed milk powder or some rennet, e.g. 0.5 to 1.0 ml per 100 l of cream is added to improve body.

After incubation, the sour cream is cooled as quickly as possible, and stored at a temperature of 5 °C or lower. If the cream is incubated in small containers, cooling is possible by placing the containers in cold store or in ice water. If the cream is cultured in bulk, it will be packaged first and cooled afterwards.

The product should be stored at the cooling temperature for at least 24, but preferably 48 hours, to allow the milk fat to solidify and thus enhance the body of the cream.

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11.2 Flavoured milks

Flavoured milks may be introduced as a possible means of increasing milk sales, especially if plain milk is not highly esteemed. In many countries the most popular flavours are chocolate and coffee; fruit flavours are less popular, although in certain parts of the world a good market is found for fruit-flavoured products. The composition of the products, especially the kind and intensity of the flavour and the sweetness of the product should be adjusted to the preferences of the consumers. All flavoured products may be made from milks of various fat contents.

Stabilizers are much used in the production of flavoured milks, to increase their viscosity and to prevent aggregation and whey separation if the acidity of the product is increased as a result of the addition of juices. Common stabilizers are gums, such as carrageenan and alginates, carboxymethyl cellulose and modified starches.

Chocolate milk

Consumers often find full-cream chocolate milk to be too rich, and prefer a product with a lower fat content or even with no fat. The basic ingredients for chocolate milk are milk, cocoa or liquor chocolate, sugar and stabilizer. A typical formula for chocolate milk is:

- 91.00% milk with 2.50% fat
- 1.50% cocoa
- 7.25% sugar (sucrose)
- 0.25% stabilizer

After the ingredients have been mixed with pasteurized milk, the mixture is homogenized. Thereafter, the chocolate milk may be pasteurized again. Pasteurization should be intense, either in batch (for instance at 70 °C for 30 minutes) or in HTST (for instance at 80 °C for 25 seconds). Finally, the product is cooled and bottled.

The major problem in the production of chocolate milk is the settling of cocoa particles in the bottle; this is generally considered to detract from the appearance of the product. Settling can be minimized by finely grinding the cocoa and by increasing the viscosity of the product by using more stabilizer. Homogenizing the milk after the cocoa has been added may also reduce settling.

Fruit-flavoured milks

Most fruit juices require a certain acidity to bring out their full flavour. An increased acidity may result in the coagulation of the casein in milk. Neutralization of the fruit juice, or the use of a 'neutral' artificial flavour may result in products that are not fully appreciated. Therefore, preference may be given to the use of stabilizers, which prevent destabilization of the product. Proper stabilizers even allow for the pasteurization of the product. See also Section 7.3: 'Preservation of yogurt'.

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11.3 Edible ices

Characteristics and composition of edible ices

Edible ices comprise foods or beverages of widely different analytical composition, including products often referred to as 'ice cream', although they do not contain a substantial amount of cream or milk fat. Ices containing fats other than milk fat are often also called 'ice cream'. Some edible ices – so-called 'water ices' – contain few or no milk ingredients, like other ices mainly manufactured from fruits and fruit juices. This section will focus on dairy ices, i.e. ices containing milk components and sugar, and only a few per cent of other ingredients. Such ices are made by freezing a pasteurized mixture of ingredients, known as mix, under inclusion of air by agitation (whipping), which gives the product the character of a frozen foam, in which only part of the water is frozen.

Two categories of dairy ice can be distinguished:

– Soft ice, which is consumed immediately or almost immediately after freezing the mix. The product is still soft and has a temperature of about −5 °C. Its keeping quality is poor.

– Hardened ice or regular ice, which is hardened immediately after freezing the mix at about −5 °C. Hardening takes place at a temperature of about −20 °C or lower. This product is much firmer (harder) than soft ice, because a much larger proportion of the water is frozen. The product can be kept for six months or longer, provided the basic ingredients are of excellent quality and a constant low temperature can be maintained. However, there is a risk that oxidative defects will occur during prolonged storage.

The mix contains a combination of dairy ingredients, sugars and, generally, a number of other components, such as stabilizers, emulsifiers and colouring and flavouring substances. The mix may be composed at the dairy plant, or be bought 'ready-to-use', usually in a dry form.

The fat in the ice gives the product its pleasant, rich flavour and contributes to its texture as a result of the formation of networks of agglomerated fat globules during

Table 21. Formulae for dairy ices.

Constituent	Genuine ice cream	Milk ice
Milk fat (%)	12.0	3.0
Non-fat dry milk solids (%)	11.0	11.0
Sucrose (%)	16.0	15.0
Stabilizer and emulsifier (%)	0.5	0.5

freezing. The fat may be derived from milk, cream or other milk products, or from butter or butter oil.

As milk and cream alone cannot contribute sufficiently to the solids-non-fat content of the ice to give the body and texture that is desirable for this group of products, extra solids-non-fat, such as condensed milk and milk powder may be added. Too high a milk solids content, however, may give the product a salty taste and increases the danger of 'sandiness'. The milk proteins contribute to the stabilization of the foamy structure of the ice. The milk solids increase the viscosity of the product, and the soluble compounds lower the freezing point. Since the non-fat solids contribute to the texture and the flavour of the ice, as does the fat, they should be in inverse proportion to the fat.

The lactose in the milk solids contributes only a little to the sweetness of the ice. Therefore, extra sugar is added. Disaccharides (cane or beet sugar) as well as monosaccharides (dextrose) are used. At the low temperatures applied in the manufacture of ice cream, the lactose solution will be supersaturated in the watery phase and part of the lactose will crystallize. To avoid 'sandiness', small lactose crystals that cannot be felt on the tongue must be formed. This can be achieved by quick freezing and by avoiding fluctuations in temperature during storage.

Emulsifiers, e.g. certain glycerides and lecithin, are added to enhance the agglomeration of fat globules, thereby contributing to the desired texture. Stabilizers, e.g. gelatin, alginates and carrageenan, increase the viscosity of the unfrozen mix, thus contributing to the body and texture of the ice. They are particularly important in low-fat ice. Flavouring agents, e.g. vanilla, cocoa or fruit flavours, and colouring agents are commonly used to give specific characteristics to dairy ices. The most popular dairy ices are genuine ice cream (with a fat content ranging from 8 to 20%) and milk ice (with a fat content not less than 2%). The composition of the mixes for the manufacture of these ices must confirm to certain rules, to meet legal and quality standards. Two typical examples are given in Table 21.

Manufacture of dairy ices

If the mix is manufactured at the plant, the various liquid ingredients are mixed at a temperature of about 40 to 45 °C, and the sugar and the other dry products are then added. If products that require a higher temperature for obtaining a proper solution or dispersion are used, the temperature is increased accordingly. After a homogeneous mixture has been obtained, it is pasteurized and homogenized; for instance for 25 seconds at 75 °C and 175 atm. The homogenized mix is cooled to a temperature of about 4 °C for a period that may vary from a few to 24 hours, during which it ages. One of the objectives of aging is to allow the fat to solidify and some stabilizers to dissolve completely or 'swell'. If a proportion of the non-fat-milk solids is replaced by sweet-cream buttermilk powder, the product acquires a creamy flavour. Commercial dry 'ready-to-use' mixes must be reconstituted before freezing. Pasteurization may be advisable. Some modern procedures for manufacturing dairy ices dispense with the need for aging the mix.

Two basic types of freezers are in use for the production of dairy ices:
- batch freezers, which are especially suitable for small-capacity operations;
- continuous freezers, which are in use for high-capacity operations.

Batch freezers. The mix is frozen in a cylinder fitted with a stirring device consisting of two parts, the scraper blade and the beater. The blades stir the mix during freezing and scrape the already frozen product from the inner side of the cylinder, returning it to the mixture still to be frozen. The beater beats air into the freezing mix to obtain the desired air inclusion. The cylinder is generally cooled by direct expansion of a refrigerant (Section 4.4). The mix will have frozen in about 8 minutes and the ice is removed manually at a temperature of about −4 °C.

Continuous freezers. In the continuous freezers, one or more horizontal cylinders are used, which are fed with a continuous flow of mix and air at one end. The mix and the air are pumped through the cylinders, where a process similar to that in the batch freezer takes place. The frozen product leaves the cylinders in a plastic state. Continuous freezing usually takes less than 30 seconds, and the ice leaves the freezer at a temperature of about −6 °C. The ice drawn from the freezers is packed into metal containers or directly into packages of suitable consumer size. Thereafter, the ice is further frozen in a hardening room at a temperature of −20 °C or lower, and stored until sales. Very large capacity installations may use continuous hardening equipment, where the ice moves through a freezing tunnel.

Special continuous freezers for the production of so-called soft-consumption ice, which is sold for consumption in a soft form almost immediately after it is drawn from the freezer, have become very popular. Dairy ice produced in batch freezers is also almost always offered for consumption without hardening.

Properties of dairy ice

Ice must contain a certain amount of air, because otherwise it would be a hard, unpalatable, solid block. The quantity of air that is whipped into the mix during freezing is known as overrun. It is expressed in percentages of the volume of the mix. In continuously frozen genuine ice cream it may vary between 75 and 100%; on average, it is lower in milk ice and in batch-frozen ices; 50 to 80% and 30 to 50%, respectively. Much higher overruns may be chosen for commercial reasons, but then the product may lack body and be 'foamy'. The correct overrun depends upon composition of the mix and the way it is produced. Mixes with high solids contents justify a higher overrun than mixes with a lower solids content.

Ices should melt in the mouth without giving the impression of being too cold. The melted product should be neither too liquid, nor too viscous. Apart from poor processing techniques, the use of too much or too little stabilizer and over- or under-whipping may be responsible for a poor melt. Large lactose crystals may be felt as sandiness on the tongue, as are large ice crystals, that are the result of poor freezing procedures and fluctuations in temperature during the storage of the ice. Such variations may also cause the product to shrink.

Hygiene

Scrupulous hygiene must be observed in the production and handling of ice cream. It is true that the development of micro-organisms comes to a standstill at the low temperatures, but any residues of the product that are left behind in equipment and other places are an excellent culture medium for a large variety of microbes after melting. All equipment and utensils must be properly sanitized after every use.

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12 Testing of milk and payment for milk

12.1 Testing of milk

Dairy plants must have adequate facilities to test the quality of milk received from farmers and other suppliers and to check the quality of the various products. Furthermore, it is important to test the quality of the water and the strength of detergents and sterilizing agents and to inspect the results of sanitization, etc. Small processing units generally lack the facilities for performing sophisticated tests and analyses, but often samples can be sent to specialized laboratories, or a number of plants may establish a central, well-equipped laboratory. A dairy laboratory must be carefully planned. Its design will partly depend on the capacity of the dairy plant and the tests to be performed.

It is beyond the scope of this book to give a full description of all laboratory tests. For this, the reader should consult specialized handbooks. Only the most important tests used to ascertain the composition and quality of fresh milk and to determine the effectiveness of the pasteurization process in the production of liquid milk are discussed below.

12.1.1 Sampling and treatment of samples

Samples from bulk milk or milk in cans should be taken after the milk has been thoroughly mixed, otherwise the sample may not be representative of the whole quantity of milk. Sample bottles are used to store the samples and to take them to the laboratory. If, in the laboratory, samples for testing are to be taken from the sample bottles, the contents of the bottle have to be mixed with the utmost care. To facilitate mixing, the sample bottle should not be filled to the brim. For fat and density tests the fat must be uniformly distributed through the sample. To achieve this, the milk fat should be in a liquid state during mixing. Therefore, the bottle with its contents is warmed to 40 °C in a water bath, kept at this temperature for a few minutes, and – only then – mixed. Thereafter, the bottle with its contents should be cooled to 20 °C and examined as quickly as possible, but before the final sample for testing is taken, the cooled bottle with the sample should be inverted several times. No air should be incorporated during the mixing, otherwise the fat-content and density test will give results which are too low.

12.1.2 Bacteriological tests

12.1.2.1 Dye reduction test

This test, the simplest method for rapidly determining the hygienic quality of fresh milk, measures the reducing ('oxygen-consuming') activity of micro-organisms. The test is based on the assumption that the higher the number of bacteria, the higher the reducing capacity of the milk. However, since not all bacteria possess a reducing activity, and those that do vary in their activity, the test merely gives a very rough indication of the number of micro-organisms. For example, water bacteria are poor reducers, but lactic acid bacteria are strong reducers (Section 2.4).

The reducing capacity of milk is measured by the time required to reduce and – at the same time – change the colour of an indicator dye. Two reduction dyes are used in the dairy industry for this purpose: resazurin and methylene blue.

Resazurin reduction test (RRM)

This dye gives a blue colour in fresh milk. As the sample is reduced, the colour changes to various shades of purple until a pink colour develops. Upon continued reduction the pink colour disappears and the sample becomes colourless. Two main systems for reading the test are in use:
- the triple reading test,
- the one-hour reading test.

Triple reading test. At appropriate intervals, stipulated by the grading system used, the colour of the samples is compared with a standard colour between the initial blue and pink (usually lavender). The sample is classified in accordance to the time used to reach the standard colour. The samples are usually read three times, e.g. after one, two and three hours. Example:

qualification of the milk	*lavender colour reached*
bad	in one hour or less
poor	between one and two hours
good	between two and three hours
excellent	after three hours

One-hour test. After one hour the colour of the sample is compared with a number of standard colours indicating various degrees of reduction. Every standard colour represents a quality degree. Depending on local conditions, a period shorter than one hour may be used for recording the change in colour of the sample.

Methylene blue reduction test (MBR)

The dye gives a blue colour to the milk, which goes to white by reduction. At appropriate intervals – stipulated by the grading system – the colour of the samples is checked. They are classified in accordance with the time used to reach the white colour. Any system of time intervals may be used. Example (the samples are read three times, that is after 20 minutes and after two and five hours):

qualification of the milk	*white colour reached*
bad	within 20 minutes
poor	between 20 minutes and two hours
good	between two and five hours
excellent	after five hours

Large numbers of body cells, or somatic cells, e.g. leucocytes in mastitis milk, will shorten the reduction time of milk. In this case, milk may be classified in a much lower quality grade than its bacterial quality merits. Other tests should be implemented to test for high cell counts.

The dye reduction tests tend to give too favourable results if deep-cooled milk is tested. As a result of the low temperature, micro-organisms are more or less in a dormant stage, depending on the time and the temperature of cooling. Moreover, the psychrotrophic bacteria that may develop in deep-cooled milk show little reductase activity (Section 2.4). For these reasons, there is a tendency to use the plate-count test (Section 12.1.2.2) for the examination of deep-cooled milk, instead of the reduction test. The plate-count test has the disadvantage that it is laborious and requires better equipped laboratories and higher-qualified staff than the rather simple reduction test.

The dye reduction test must – like all bacteriological tests – be performed under sterile conditions, which means that contamination must be avoided and that all glassware, dippers and stoppers must be sterilized before use. Glassware for the reduction test may – as an alternative – be 'sterilized' by being submerged in boiling water shortly or immediately before use. After every sample, the dipper used for sampling must be rinsed in clean water and then 'sterilized' in hot water (85 °C) for at least one minute, or in a sterilizing solution (e.g. 100 to 150 ppm active hypochlorite in water) for at least 30 seconds. The dye solutions and nutrients must be sterile.

Carrying out a dye reduction test

20 ml of a thoroughly mixed sample is put into a test tube, and 0.5 ml of the dye solution (0.0075% methylene blue) is then added. The dye and the milk are mixed by inverting the test tubes which are closed by stoppers or caps. A mixture can also be obtained

by putting the dye solution in the test tube before adding the milk sample.

The test tubes are kept in a water bath of 36-38 °C and are protected against light. Colour changes are read at intervals stipulated by the grading system. The test tubes may be inverted at regular intervals during testing.

12.1.2.2 Standard plate count

This is the most accurate method for counting live micro-organisms in raw and heat-treated milk. The method consists of mixing a sterile solution of a special liquidized agar medium with a certain quantity of the sample in a sterile Petri dish. Because of the agar, the nutrient is solid at room and incubation temperature, but is liquidized before use by being immersed in hot (or boiling) water. After cooling the nutrient agar to about 50 – 55 °C, it is mixed with the sample in the Petri dish (Figure 69) and allowed to solidify and then incubated at a temperature of 37 °C for two days, or at 30 °C for three days. Thereafter, the microbes that have developed into colonies are counted. Best results are obtained when the number of colonies per dish is between 30 and 300. Higher counts are prevented by making dilutions of the sample by transferring (if necessary, repeatedly), 1 ml of the sample (or the preceding dilution) into 9 ml buffered distilled water or sterile water containing 0.8% NaCl (common salt), until a solution is obtained that is expected to give a plate count between 30 and 300. The actual plate count is calculated by multiplying the count on the dish by 10^n, in which n stands for the number of consecutive dilutions of the original sample.

The standard plate count is an empirical method, because some micro-organisms will not be able to form visible colonies under the conditions of the test, because of an unfavourable incubation temperature, the presence of oxygen, lack of essential nutrients, etc. Moreover, micro-organisms occurring in groups will form only one colony. For these reasons, the number of colonies that develop is always smaller than the actual number of microbes. Nevertheless, the method is generally accepted as the standard counting method.

Psychrotrophic bacteria count

Psychrotrophic bacteria, which are especially found in deep-cooled milk, are destroyed by normal pasteurization, but easily reintroduced by recontamination. They are the major cause of defects in pasteurized milk stored under refrigeration for longer periods. Enzymes formed by these bacteria are very heat resistant and consequently are

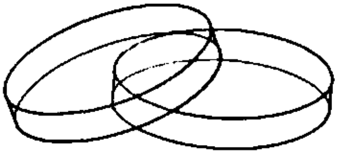

Fig. 69. Petri-dish.

responsible for deterioration of UHT milk (Section 6.5). The number of psychrotrophic bacteria in milk can be counted by incubating the plates of the standard plate count at a temperature of 7 to 8 °C for 5 to 7 days.

The value of this test for fresh milk is often questioned because at the generally accepted 'standard temperature' of deep-cooled milk (4 to 5 °C), fewer bacteria develop than at 7 to 8 °C. The latter temperature is closer to the normal temperature of a household refrigerator. Moreover, it is not easy to maintain a constant temperature as low as 7 to 8 °C (let alone of 4 to 5 °C) in a laboratory incubator, which is often opened.

Thermophilic bacteria count
Thermophilic bacteria are able to develop in milk at temperatures of 55 °C and sometimes higher. Their presence in milk and in food products containing milk can lead to deterioration if these products are stored at high temperatures. If present in milk, they can be counted by incubating the plates of the standard plate count at a temperature of 55 °C for two days. Mesophilic bacteria will not develop at that temperature, and the thermophilic bacteria will not develop at the normal incubation temperature of the standard plate count. However, sometimes the latter show some growth, leading to the development of tiny colonies called pin-points.

Other modifications of the standard plate count are used for counting thermoduric bacteria, spores, anaerobic bacteria, yeasts and moulds.

12.1.2.3 Coliform count

Coliform counts are only useful for the grading of raw milk if standards of milking and milk handling are extremely high. In all other cases the test is of no or little value for fresh milk since coliforms will be present anyway. Sometimes, special analyses are performed to search for the intestinal, potentially pathogenic type of coliform, *Escherichia coli*.

Since coliforms are killed at normal pasteurization temperatures, their presence in pasteurized milk indicates inadequate treatment or recontamination. For this reason, coliforms should be absent in pasteurized products.

The larger the quantity of milk that is examined, the greater the probability that coliforms will be found. Accordingly, many countries require absence in 1 ml of pasteurized milk, but other countries are satisfied with absence in 0.1 ml.

Coliform tests are either performed in liquid or in solid media that contain nutrients for the development of the coliforms and one or more ingredients for suppressing the growth of other bacteria. For routine analyses, the quantity of milk in which no coliforms should be present is transferred to a fermentation tube containing 10 ml of the sterilized liquid medium, provided with a small tube with the closed side pointing up wards (Figure 70). The tubes are incubated at 30 °C for two days. If coliforms are present they will produce gas that raises the small tube in the liquid.

With a multiple-tube method, various dilutions (such as categories for 0.1 ml, 0.01 ml and 0.001 ml) are transferred to several (e.g. 5) test tubes. The number of tubes

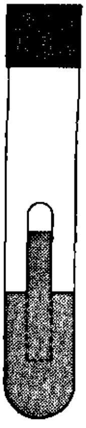

Fig. 70. Coli test tube.

with gas formation in every category indicates the number of coliforms. The most probable number can be read from a table. This method is rather complicated. It is simpler to use an agar plate method, which is similar to the standard plate count, but which uses a different medium.

All media necessary for the performance of bacteriological tests are obtainable from firms that specialize in the production of bacteriological media.

12.1.3 Physico-chemical tests

Sediment test

The amount of dirt in milk, such as soil, dust, feed particles, manure, hairs, etc., is *usually tested by filtering a certain* quantity of milk (200 to 250 ml) through a pad or disc of cotton or similar material. The quantity of dirt collected on the filter is a measure of the cleanness of the milk. Milk that has been filtered on the farm will no longer contain large dirt particles, but only very fine dirt has passed through the filter. This dirt will not pass through the discs at the laboratory, because these discs are more dense than the filters used at the farm. Because of their denseness, milk must be sucked through the laboratory discs by vacuum. Standards consisting of discs with a certain amount of sediment are often used for comparing and grading samples.

As an alternative to this test, a small quantity of milk can be centrifuged in a special test tube that ends in a capillary, where the deposit can be measured volumetrically (Figure 71). Apart from dirt, some micro-organisms and somatic cells will also be collected in the sediment test tube. Dirt gives the sediment a greyish-black colour; a large amount of somatic cells gives a yellowish sediment, which may indicate mastitis. Milk with an increased acidity may be responsible for a large amount of white sediment, consisting of destabilized casein. The deposit can be examined microscopically.

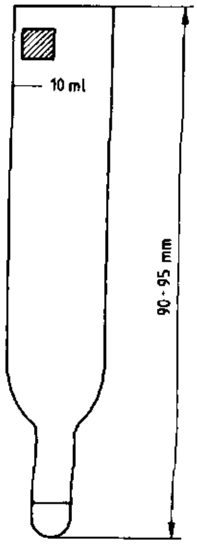

Fig. 71. Sediment test tube. Courtesy: Royal Netherlands Dairy Federation (FNZ).

Flavour

The flavour of milk can be examined by filling a sample bottle for two-thirds with the milk to be tested, closing it with a glass stopper and putting it in a water bath of 30 °C for 10 minutes. The stopper is then removed and the milk is smelt and graded.

Mastitis tests

Milk from animals suffering from mastitis usually shows a number of abnormalities, such as a high catalase activity, a high somatic cell count, and an increased chloride content and a lowered lactose content. Two tests based on methods to examine these abnormalities have been used to detect mastitis milk, but neither of these is fully reliable.

Catalase test. The catalase test is based on the liberation of molecular oxygen after hydrogen peroxide has been added to milk. By collecting the oxygen in a specially shaped test tube (Figure 72) the presence of increased catalase activity can be measured. There are other possible causes of an increased oxygen production; e.g. milk produced at the end of the lactation period may have a high catalase activity.

California mastitis test. A simple practical method for the detection of a high count of somatic cells is known as the California mastitis test (CMT). If a mixture of equal quantities of the suspected milk and the CMT reagent (a 3% solution of sodium lauryl-

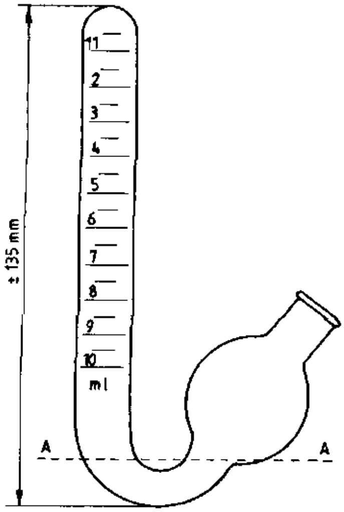

Fig. 72. Catalase test tube. Courtesy: Royal Netherlands Dairy Federation (FNZ).

sulphate with pH 11) becomes viscous, the milk has a high cell content.

Several methods are available for counting somatic cells electronically.

Phosphatase test

Normal HTST pasteurization inactivates the alkaline phosphatase in milk (Section 6.1). Its presence indicates no or improper pasteurization, or recontamination with unpasteurized or insufficiently pasteurized milk (although the inactivated enzyme has been known to reactivate under certain conditions). The test is based on the ability of phosphatase to liberate phenol from a phenol-phosphate substrate added to milk. Therefore, the milk is tested for the presence of liberated phenol. Since the amount of liberated phenol is proportional to the amount of enzyme, the test can be used for determining the quantity of phosphatase available in milk.

Storch's peroxidase test

The peroxidase enzyme is inactivated in a few seconds at a temperature of 80 °C or higher. Its presence in milk indicates that the milk is raw or has been less heat treated (e.g. HTST-pasteurized milk), or that the milk treated at 80 °C is contaminated with raw milk or with milk treated at a lower temperature. The test is based on the ability of peroxidase to liberate oxygen from hydrogen peroxide added to the milk. The oxygen oxidizes the colouring agent p-phenylenediamine, thus producing an intense blue colour.

Titratable acidity

The alcohol test and the clot-on-boiling test (Section 5.2) give a rough indication of the acidity of milk. An accurate measure of the acidity can be obtained by determining the pH of the milk with a pH meter or by ascertaining the titratable acidity.

The titratable acidity of milk is determined by titrating a certain quantity of milk with a standard alkaline solution, usually 1/9 N NaOH, in the presence of phenolphthalein as a colour indicator. At the point of neutralization the white colour of the milk changes to pink. Either an ordinary burette or an acidimeter specially calibrated for this test can be used. The quantity of 1/9 N alkaline solution in ml needed to neutralize 100 ml of milk is the titratable acidity, expressed in degrees Dornic (°D), in which case 1°D corresponds to 0.01% lactic acid (see Section 2.3)[1]. Actually, the term 'lactic acid' is not correct, because the sodium hydroxide (NaOH) is also bound by other components of the milk.

The quantity of indicator added to the milk affects the result of the test. Therefore, this quantity should be standardized for accurate titration.

12.1.4 Tests for the determination of residues

Antibiotics

Several tests are applied to examine milk for the presence of antibiotics, usually penicillin. They are based on the hindrance of the development of certain types of micro-organisms by the antibiotics.

The simplest method of testing milk is to inoculate boiled milk with 2% of a yogurt culture and to incubate the mixture at 37 °C. If the milk does not curdle within 3 hours there is every likelihood that it contains penicillin (at least 0.05 IU).

Another method uses an agar medium inoculated with a micro-organism (usually *Bacillus calidolactis*), which is solidified in a Petri dish (compare standard plate count). A filter-paper disc, saturated with the milk to be tested, is placed on the medium. Then the Petri dish is placed in an incubator at 55 °C for 3 hours. The growth of the micro-organisms will be inhibited around the paper disc, if the milk has been contaminated by penicillin. The antibiotic diffuses from the paper disc into the medium, where it prevents the growth of micro-organisms.

Oxidants and pesticides

Tests to examinate milk for oxidants and pesticides (Section 2.2) are complicated and require a well-equipped laboratory.

[1] Standard alkaline solutions of 0.25 N (0.25 mol/l) and 0.1 N (0.1 mol/l) may also be used, expressing the acidity in degrees Soxhlet-Henkel (°SH), and degrees Thörner or degrees normal (°N) respectively. So, 1 °SH = 2.5 °N = 2.5 °T = 2.25 °D.

12.1.5 Tests for the composition of milk

Fat content

There are two volumetric methods for testing the fat content of milk, namely the Gerber and the Babcock tests. The Gerber test is most often used.

Gerber test. 10 ml of concentrated sulphuric acid (density at 20 °C 1.816 ± 0.003 g/ml), a certain volume of milk (usually 11 ml, but sometimes less) and 1 ml of amyl alcohol (density at 20 °C 0.811 ± 0.002 g/ml) are successively put into a specially-shaped test tube with calibrated stem, called a butyrometer. After a rubber stopper has been inserted, the butyrometer and its contents are vigorously shaken with the stem downward, for about 30 seconds. Then the butyrometer is turned end-over-end a few times to mix the contents of the stem with those of the body, and the butyrometer is shaken again. At the end of the shaking and mixing procedure all proteins should be dissolved. Since the mixing of milk and sulphuric acid results in a considerable increase in temperature, the butyrometers are cooled in a water bath of 65 °C

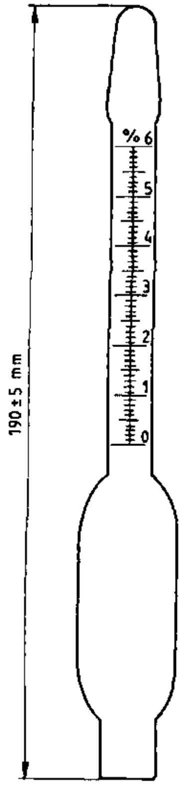

Fig. 73. Butyrometer. Courtesy: Royal Netherlands Dairy Federation (FNZ).

for 5 minutes with the stoppers downwards. Thereafter, the butyrometers are spun in a special Gerber centrifuge for three minutes at 1100 rpm with the stoppers outwards. Milk fat separates from the heavy acid solution and collects in the calibrated stem (Figure 73). Since the temperature of the butyrometers drops during centrifugation and the butyrometers are standardized for reading at 65 °C, they are put back in the water bath for another 5 minutes. Thereafter, the volume of fat can be read off from the calibrated stem. The rubber stoppers must be pushed inwards or pulled outwards a little if the fat-acid interface is not in the calibration of the stem. To obtain accurate results, the chemicals for this test should be of the correct purity and composition.

Warning: Great care must be taken when using concentrated sulphuric acid, because it is extremely aggressive to the skin. It may cause blindness if it gets into the eyes. Therefore, goggles should be worn during the reading of butyrometers. Mixing sulphuric acid and water is accompanied by heat development. The acid should always be added to the water carefully and gradually and water should never be added to the acid, because, as a result of the heat development, water will evaporate in the acid instantaneously, which may result in an explosive spluttering of the acid.

When reading the quantity of fat in the calibrated stem of the butyrometer, the fat in the meniscus (0.07%) is not taken into consideration; in other words, the meniscus is not read off. Consequently, the method is not accurate for low and high fat contents: the former gives values that are too low, the latter gives values which are too high. This

Table 22. Scale of corrections for readings of the fat content of milk on butyrometers.[1]

Reading (%)	Correction (%)
0 – 0.25	+0.07
0.26 – 0.75	+0.06
0.76 – 1.25	+0.05
1.26 – 1.75	+0.04
1.76 – 2.25	+0.03
2.26 – 2.75	+0.02
2.76 – 3.25	+0.01
3.26 – 3.75	0
3.76 – 4.25	0
4.26 – 4.75	–0.01
4.76 – 5.25	–0.02
5.26 – 5.75	–0.03
5.76 – 6.25	–0.04
6.26 – 6.75	–0.05
6.76 – 7.00	–0.06

[1] In accordance with domestic legislation in the Netherlands, using – amongst others – a milk pipette of 10.77 ml.

may erroneously indicate fat losses in dairy plants where milk with high fat contents, e.g. buffalo's milk, is processed; especially in plants where the milk is standardized or skimmed, and large quantities of cream are used for making butter or ghee. The quantity of fat found in the raw milk will be higher than the total quantity found in the standardized and skimmed products and in the butter or ghee. In such cases it is advisable to adjust the glassware to eliminate the deviations resulting from the higher fat contents, or to introduce a scale of corrections. The adjustments mentioned earlier may lead to inaccurate results if milk of widely varying fat content is received, and if the glassware for milk with high fat contents is also used for the standardized products without introducing corrections. It is therefore preferable to use a scale of corrections (Table 22).

Milkotester

As might be expected, automatic techniques have been developed to undertake routine tests such as testing for butterfat. The Milkotester now offers a quick and easy method. Basically, a reagent consisting of disodium ethylene diamine tetracetic acid (EDTA) and sodium hydroxide together with an antifoaming agent are added to the milk sample and the mixture is homogenized. The EDTA reagent takes into solution all the components of milk, except for the homogenized fat globules, which remain in suspension, making the mixture turbid. The sample is then put in a small glass chamber and the concentration of fat globules in suspension (the turbidity) is determined by passing light of a certain wavelength through the mixture. The light that passes through the mixture is recorded by a photoelectric cell and is directly related to the amount of fat present. The Milkotester automatically converts this reading into a percentage that may either be shown on a digital display panel or on an automatic print-out. Although this technique greatly simplifies the fat test, a skilled technician is still needed to check the calibration of the equipment against the Gerber test, make up the reagent and prepare the samples.

Protein content

Several methods are available for testing the protein content of milk. Many laboratories use the so-called dye-binding methods. In these tests a certain quantity of milk and a suitable dye are mixed. The protein combines with the dye and forms insoluble dye-protein complexes. Determining the residual amount of dye and deducting this quantity from the quantity originally added, will give the quantity bound by the proteins. The latter is a measure of the protein content of the milk.

Special high-capacity equipment has been developed for completely automating the estimation of the fat, protein and lactose contents of milk.

Density

After the milk sample has been thoroughly mixed, it is poured slowly down the side

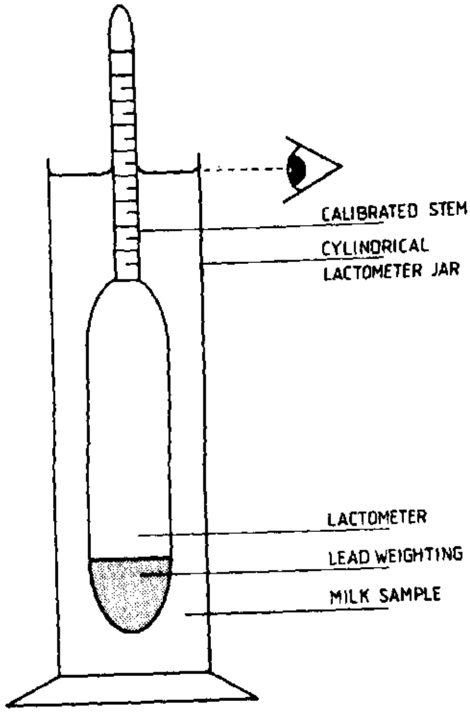

Fig. 74. Lactometer. Courtesy: Royal Netherlands Dairy Federation (FNZ).

of a cylindrical hydrometer jar until the cylinder is completely full. A hydrometer (lactometer) is then gently inserted in the sample and released. As soon as the lactometer comes to rest, the scale reading corresponding to the liquid level is read off (Figure 74). The milk should have a temperature of 20 °C at the moment of reading. The lower the density of the milk, the deeper the lactometer will sink and the lower the reading on the calibrated stem of the lactometer will be (Section 5.2). The calibration usually runs from about 20 to about 40. A reading of 30 indicates a density of 1.030 g/ml.

Solids content

Various formulae in which the milk fat content and the density of the milk are combined are used to calculate the approximate solids content. The following formula is used in the Netherlands:

$$TS = 1.23\,F + 2.6\frac{100(d_{20} - 0.9982)}{d_{20}}$$

in which:
TS = total solids content (weight percentage)
F = fat content (weight percentage), using a pipette with a capacity of 10.77 ml)
d_{20} = density at 20 °C

The solids-non-fat content of milk is found by deducting the milk fat content from the total solids content.

12.1.6 Tests to indicate adulteration of milk

The extraction of cream and the addition of water are the principal forms of adulteration of milk.

Extraction of cream

The extraction of cream from milk cannot be proved in a laboratory. Very low fat contents are an indication of such an extraction.

Addition of water

Measuring the density of milk is a very rough method of detecting adulteration with water (Section 5.2). The most reliable method is to determine the freezing point, which is very constant, but varies slightly between milk from different species. The test is performed by freezing milk in the low-temperature bath of a cryoscope and reading off the freezing point from a special, very accurate thermometer. Originally, the test was very complicated, but with modern cryoscopes the test has been made automatic and the freezing point can be read from a measuring dial.

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12.2 Payment for milk[1]

Basically, milk should be paid according to its:

- quantity,
- composition, and
- hygienic quality.

If he is paid solely according to quantity, either expressed in litres or kilograms, the supplier may be tempted to adulterate the milk by adding water and/or extracting cream. To make it less attractive to him to skim the milk, the milk supplier can be paid according to quantity and fat content, e.g. by paying him a basic price per kg or l of milk and an additional sum of money depending on the fat content of the milk. Under this system, the price farmers receive for high-fat milk is higher than for low-fat milk, which seems correct, because milk fat is considered to be a valuable component of milk (for instance for the production of butter and ghee).

Payment on protein (or SNF) content can be introduced in the same way, because milk with a high protein (or SNF) content has a higher value in the manufacture of many products than milk with a low protein (or SNF) content. Payment on quantity in combination with fat content and protein (or SNF) content is very complicated and it will still make adulteration with water profitable for the milk supplier; therefore the introduction of a system whereby the milk is paid for solely according to the quantities of fat and the quantities of protein (or SNF) supplied, can be considered.

Samples should also be taken so that the milk can be examined for its hygienic quality. The appropriate tests were described in Section 12.1. The result of every test can be rated by giving a score. The milk can be classified according to quality, by totalling the scores given for the individual tests. Financial bonuses or penalties can be awarded for the various quality classes.

Samples for bacteriological tests may never be preserved.

[1] Systems of payment for milk, their introduction and implementation will be discussed comprehensively in the companion volume 'Strategy for dairy development in the tropics and subtropics'.

13 Sanitization

13.1 *Principles of sanitization*

For the production of clean milk and milk products of high bacteriological quality, all surfaces of dairy equipment that come into contact with these products directly or indirectly must be properly cleaned and sterilized. Since the equipment is the major source of contamination, the risk of poor-quality milk and milk products increases with the amount of equipment. Cleaning, that is the removal of dirt and milk deposits after processing, is necessary because otherwise the equipment will form an excellent medium for the development of micro-organisms, which will later contaminate the next production. After cleaning, all surfaces that come into contact with milk or milk products must be sterilized to destroy micro-organisms and enzymes that have survived the cleaning procedure. The sterilization of improperly cleaned equipment is less effective, because dirt and milk residues may protect micro-organisms against disinfection, and disinfectants can be inactivated by the residues.

Cleaning and sterilization are two complementary processes. Cleaning without disinfection will not give satisfactory results; neither will disinfection without cleaning. The combination of the two activities is named sanitization. Each process requires its particular chemical compounds, but products that successfully combine both activities, at least if the surfaces are not too soiled, are available.

The sanitization of dairy equipment should basically consist of the following procedures:
- a pre-rinse with cold or lukewarm water,
- cleaning with an alkaline and/or an acid detergent,
- an after-rinse,
- sterilization with a disinfectant or with heat,
- drying the equipment.

13.1.1 Pre-rinse

A thorough pre-rinse is necessary to remove as much of the dirt and milk residues as possible. All residues that are left behind will increase the consumption of detergents, because they neutralize their effectiveness. Moreover, residues subjected to high temperatures in a later stage of the sanitization process may form persistent deposits.

Dirt on the outside of the equipment has to be removed, not only for psychological reasons but also because it will contaminate the hands of the milker or the milk processer and via his hands the milk itself or the surfaces that come into contact with the milk.

13.1.2 Cleaning

For proper cleaning, detergents must be used. The type of detergent and its concentration not only depend on the degree of dirtiness but also on a large number of factors, such as:

- kind of dirt,
- whether the cleaning is manual or mechanized,
- type of equipment and the material it is made of,
- quality of the water,
- availability of steam or hot water.

A large number of detergents is available for cleaning. Some consist of simple chemicals that the user may combine to form more composite products. Other detergents bear trade names and their composition is often unknown, but they are usually a blend of inorganic agents, water softeners and wetting agents. In many cases they are especially effective for specific purposes. The manufacturer's instructions for use should be followed precisely to obtain good results. Detergents can be classified into two groups, namely the alkaline and the acid detergents.

Alkaline detergents

The principal activity of this category of detergent is the dissolution of the milk proteins and the saponification of the milk fat, so that the deposits can be removed from all surfaces. The strongest and most effective alkali is caustic soda or sodium hydroxide (NaOH), but for certain applications it is too biting and corrosive, and less strong alkalis, such as soda-ash (Na_2CO_3) and trisodium phosphate ($Na_3PO_4 \cdot 12\ H_2O$) and sodium metasilicate ($Na_2SiO_3 \cdot 10\ H_2O$) or mixtures of these are used.

The disadvantage of strong alkalis is their corrosive action on metals. Stainless steel is absolutely resistant to alkali, unless excessive concentrations and temperatures are used. Aluminium however, is corroded by caustic soda, soda-ash and trisodium phosphate, but adding water-glass (an alkaline colloidal solution of silicates containing about 8% Na_2O and 30% SiO_2) to these alkalis will prevent corrosion. To 1 l of a 1% NaOH solution about 60 ml water-glass has to be added, but much smaller quantities will be sufficient for soda-ash solutions, e.g. only 0.5 to 1.0 ml water-glass per l. Sometimes, sodium metasilicate (a solution containing 20% N_2O and 20% SiO_2) is added to the alkaline solution to protect aluminium against corrosion. It is less effective than water-glass, and about 0.5% will be necessary if solutions of soda-ash are used, but it does not give sufficient protection if added to caustic soda. The tin used to coat various metals is not very resistant to alkalis, especially not in the presence of air (oxygen). The addition of 25% sodium sulphite to caustic soda or 10% to soda-ash will considerably limit the corrosion.

The concentration of alkaline solutions can be expressed as 'percentage NaOH', to be determined by neutralizing 10 ml of the washing solution with 0.1 N hydrochloric acid against phenolphthalein. One ml of hydrochloric acid then corresponds to a concentration of 0.04% NaOH.

For manual cleaning the alkaline solutions should not be too strong, e.g. no stronger than 0.25% of soda-ash, otherwise they will be too aggressive to the skin. For the same reason, the temperature should not be too high, e.g. no higher than 40 °C. Much stronger solutions can be used to clean stainless steel equipment by circulating the detergent through the system of pipelines and equipment (cleaning-in-place, or CIP), e.g. 2 l of a commercial solution, containing 33% caustic soda, per 100 l of water. The concentration largely depends on the quantity of milk deposits on the surfaces. Pipelines used solely for cold milk require lower concentrations than heat exchangers. An alkalinity of 0.2 to 0.3% NaOH will generally be sufficient for pipelines but for very dirty equipment, like pasteurizers including their pipelines, concentrations with an alkalinity of up to 1.0% and even higher may be used.

The temperature for alkaline CIP should be about 70 °C.

Milkstone

After saponification and dissolution, the milk fat and the milk proteins are washed away during cleaning, together with most of the other deposits on the surface of the equipment. However, a film invisible to the naked eye – especially if the surface is wet – may remain behind, particularly if high temperatures are used. This film mainly consists of deposits of hard water and minerals of milk, but it can also include other milk components. The film gradually becomes thicker and at a certain moment its presence will be noticeable; it is now called scale or milkstone. In heat exchangers this scale will act as an insulator, decreasing the efficiency of heat transfer. Milkstone will also provide bacteria with an excellent hiding place, protecting them against sterilizing agents. Bacteria may even develop in milkstone if nutrients remain and the stone does not dry, thus contaminating the product in the new shift. The type and the thickness of the deposit depend on a number of factors, such as temperature and time of contact with the liquids, kind of milk products, type of cleaning solution, hardness of water, system of cleaning, etc. The scale has the tendency to harden gradually. It is important to prevent scale formation as much as possible and to remove deposits as quickly as possible.

Acid detergents

To remove milkstone, the surface of the equipment can be soaked in strong solutions of caustic soda or metasilicate, with the objective of softening the deposits, after which attempts can be made to brush them off. This method is not very effective, and the hard, abrasive materials used for brushing may damage the surfaces of the equipment. Chemical removal by brushing with an acid detergent or, preferably, circulating or spraying it, is more effective and is commonly encountered.

The disadvantage of acid detergents is their corrosiveness, which makes them unfit for a number of metals. The most effective agent against scale formation is hydrochloric acid, but this is too corrosive for tinned brass or copper and iron. Therefore, less aggressive solutions of phosphoric acid and some organic acids are often preferred. Stainless steel is very resistant to phosphoric and nitric acids, but solutions containing as little as 1% hydrochloric acid may damage stainless steel, although the composition of the steel plays an important role. The need to use acids should be prevented as much as possible by taking proper precautions to minimize scale formation. If acids have to be used, they must be handled with great care, and for safety's sake the instructions of the supplier of the equipment must be scrupulously followed.

In most dairy plants using stainless steel equipment it has become a standard procedure to wash the equipment with both an alkaline detergent and an acid detergent. The latter will either be nitric or phosphoric acid in a solution that generally contains 0.3 to 0.5% of the acid; the temperature of the washing does not exceed 65 °C. Some manufacturers advocate starting with an acid solution, followed by an alkaline one, but in most cases the alkaline solution is used first. After the acid solution has been removed, the equipment may be rinsed with a weak alkaline solution, to neutralize the acid. Rinsing the equipment with clean water between two washings partly prevents the second solution being neutralized by the first one.

Equipment that is insufficiently resistant to corrosion must never be subjected to daily washings with corrosive acid detergents. Such detergents should not be applied more than once, or, at the utmost, twice a week, and special descaling treatments should only take place if absolutely necessary. This rule is applicable both at farm level and at industrial level.

Wetting agents

Wetting agents – usually sulphonated alcohols – may be added to detergents to improve their effectiveness. The agents promote the contact of the detergent with the surface to be cleaned, and they also aid in the saponification and deflocculation of the deposites on the surface of the equipment.

Water hardness

The dissolved calcium and magnesium salts in hard water used for cleaning will precipitate during cleaning with caustic soda and soda-ash, which will favour scale formation. Therefore, water for washing solutions should be softened before use (Section 4.2), or certain chemicals should be added to the washing solution. The quantity of these chemicals depends on the hardness of the water, but adding 100 to 150 g of trisodium phosphate or 50 to 100 g of polyphosphates to 100 l of water will generally give good results. The calcium and magnesium compounds precipitated when these phosphates are used are less objectionable than those formed with caustic soda and soda-ash, because they do not give rise to scale formation; instead, floccules that are more easily rinsed off with the washing solution are formed. The same applies to the precipitates resulting from the use of sodium metasilicate.

13.1.3 Sterilization

The equipment must be sterilized by heat treatment or with chemicals to kill the micro-organisms left behind after cleaning.

Heat treatment

The application of hot air or steam has the advantage that places that are difficult to reach with chemicals, such as seams, corroded surfaces, scales of milkstone, etc., can be heated to high temperatures, thus killing any micro-organisms present. Moreover, the equipment will dry quickly, as a result of the high temperatures. This reduces the possibility of subsequent development of bacteria. Small pieces of equipment can be steamed in special cabinets. Otherwise, steam may be introduced into the pipeline system that connnects the various parts of equipment. Containers, such as tanks and cans, can be sterilized by steam injection, provided that the construction of the equipment is such, that it is able to withstand the heat treatment. In all cases, care must be taken to ensure that all parts of the equipment that will come into contact with milk or milk products reach a sufficiently high temperature, and are kept at that temperature for a sufficient period of time, e.g. 2 to 3 minutes. The importance of the time factor is often underestimated. As soon as the steam is released from the equipment, the temperature drops to 100 °C and lower, which is not sufficient to destroy bacterial spores. A more intensive heat treatment is required to destroy micro-organisms and spores when they are in a dry situation than when they are in a liquid.

Sterilization with steam has the disadvantages that it requires an installation for raising steam and that it increases the humidity of the atmosphere in the plant.

Where steam raising is not possible, hot water of at least 85 to 90 °C can be used. The equipment should be in contact with the water for sufficiently long periods of time, i.e. much longer than in the case of steam sterilization. There is a risk that thermoduric bacteria will survive hot-water sterilization, whilst bacterial spores will not be destroyed.

Except for a few applications, sterilization with hot air is not very practical.

Disinfectants

Sterilization by disinfectants has almost completely superseded sterilization by steam, especially in milk plants. The most popular disinfectants are chlorine-containing compounds, quaternary ammonium compounds (QAC) and iodophors.

Disinfectants may be used either immediately after the last residues of the alkaline or acid washing solution have been removed, or immediately before processing starts again, generally the next day or in the next shift. If equipment has been cleaned by washing with comparatively warm and strong solutions of alkalis and acids, disinfection immediately thereafter may not be considered a necessity, because the washing solutions will have killed almost all microbes, and a disinfection immediately before the next processing starts may be more useful. This system has the further advantage that the equipment will not be exposed to the sometimes corrosive disinfectants over long periods, although this danger should not be overestimated, since the most aggressive disinfectants (hypochlorites) decompose quickly after use.

It has long been believed that the separate use of detergents and disinfectants is essential to obtain good results, because the effect of most disinfectants is more or less neutralized by the presence of organic matter. In practice, however, it has been shown in many cases that the efficiency of combined compounds is good enough to make separate treatment with detergents and disinfectants unnecessary, especially if the equipment has not become too dirty. Many commercial sanitizing compounds contain both chemicals. Such compounds are replacing sanitization programmes that use a succession of different detergents. The instructions for their use as given by the manufacturer or supplier should be stricktly followed.

Chlorine-containing compounds

Hypochlorites are the longest known and probably most used chemical disinfectants. They have a number of advantages; they are:

- cheap,
- non-toxic in the concentration used,
- effective against all types of micro-organisms.

Hypochlorites corrode tinned copper and steel, and aluminium. Therefore, the concentration of available chlorine should not surpass 150 mg/l (150 ppm) for tinned copper and steel, and 100 mg/l for aluminium. The temperature of the solution may not exceed 40 °C. The corrosiveness can be limited if 0.1-0.3% of metasilicate is added to the solution. Stainless steel is much more resistant; nevertheless, it is best to avoid concentrations over 200 mg/l. A contact time on clean surfaces of 1 to 3 minutes may be applied, depending on the concentration of the solution and the quality of the stainless steel.

To protect the skin in manual sanitization, the concentration of the chlorine solution should be lowered to 100 or even 50 ppm active chlorine per litre.

The two hypochlorites most commonly used are calcium hypochlorite (available as a solid) and sodium hypochlorite (available as a solution with concentrations generally up to 17% of available chlorine). Sodium hypochlorite has the disadvantage of being bulky, but it is easily mixed with water and – contrary to calcium hypochlorite – leaves no scale on the equipment. Sodium hypochlorite may be 'included' in the crystallization water of some alkaline compounds like trisodium phosphate, thus providing the possibility of producing solid compounds that combine the properties of an alkaline detergent and a chlorine disinfectant. Hypochlorites are most active in acid solutions, but more stable in alkaline solutions.

If alkaline hypochlorites come into contact with acids, the alkaline solution will be neutralized and free chlorine will be liberated. This gas is extremely poisonous. For this reason, acid detergents should be washed away completely, before disinfection with hypochlorites starts.

Chloramines – combinations of chlorine and ammonia – are fairly stable powdered disinfectants. They release the chlorine more gradually than the hypochlorites, are less corrosive and find several applications in the dairy industry.

Quaternary ammonium compounds
Quaternary ammonium compounds (QAC's) are non-corrosive and odourless disinfectants, which gives them an advantage over hypochlorites, but they are more expensive and not always as effective against all types of microbes. They are more effective against Gram-positive than against Gram-negative bacteria, such as species of the genus *Pseudomonas.* The QAC's are preferably sold as a component of combined mixtures, which may contain water softeners, because the efficiency of QAC's is reduced in hard water.

Iodophors
Iodophors consist of iodine – which as such is an effective but corrosive element – complexed with a wetting agent, which makes the products usable in the dairy industry. They are stable and exert a powerful germicidal effect, especially in combination with an acid. Hard water does not affect their efficacy.

13.1.4 Drying the equipment

It is important to dry the equipment after sanitization, to avoid the risk of the development of microbes that have been left behind in or on the equipment, or that may have contaminated the equipment through the air or otherwise. For micro-organisms to be able to develop, sufficient nutrients must have been left behind.

Sterilization of the equipment by steaming has the advantage that the surfaces dry very quickly, provided the condensate of the steam can drain off completely. A similar situation may occur if the equipment is 'sterilized' with hot water. It is less certain that equipment will dry after sterilization with a disinfectant, and it is conceivable that microbes will grow after incomplete removal of milk residues if the atmosphere is humid, and especially if the disinfectant decomposes quickly. This re-emphasizes the importance of thorough sanitization, i.e. the complete removal of all residues and the destruction of all micro-organisms.

Sometimes, utensils and equipment are given a final rinse after cleaning or sanitization. If the water for this rinse is cold or only lukewarm, quick drying will be hampered. Moreover, poor-quality water may adversely affect the outcome of the sanitization process and it may contribute to a high count of 'water bacteria' in the products (Section 6.5).

Further reading

See Section 13.3

13.2 Sanitization at farm level

Under less primitive conditions of milk production, several methods for sanitization may be practised, depending partly on tradition and partly on the type of utensils and equipment used. The means of sanitization (detergents, hot water, etc.) available and whether the sanitization is manual or mechanical are also important.

Alkaline detergents, especially soda-ash or products with trade names are used for manual cleaning. The concentration of these solutions should not be too high, e.g. equivalent to a 0.25 or at the utmost a 0.50% solution of soda-ash. Higher concentrations will be too alkaline for the skin. A suitable temperature for the washing solution is 40 °C. After the utensils have been cleaned, they should be rinsed with hot water in such a way that all surfaces that come into contact with milk will reach a temperature of at least 80 °C; they should be kept at this temperature for at least another minute or two. This rinse will remove the detergent and 'sterilize' the equipment at the same time.

Another possibility is chemical sterilization with a disinfectant. Hypochlorites, especially sodium hypochlorite, are probably the most commonly used disinfectants, but other products such as organic chlorines, quaternary ammonium compounds, iodophors and special brand products are also on the market. Sodium hypochlorite may be used in concentrations of up to 150 ppm active chlorine at a maximum temperature of 35 °C, if the skin is protected in the event of manual cleaning, otherwise the concentration must be much lower, e.g. 50 ppm or even less. For other products, the manufacturer's instructions must be followed.

Detergents with a combined cleaning-sterilizing activity usually contain substances that improve the cleaning and sterilizing activity. These products facilitate the sanitization procedure and may give better results than the traditional sanitization methods with separate cleaning and sterilization. However, they are more expensive. When a combined sanitizing agent is used, the disinfectant starts to work even during the brushing of the utensils or the circulation of the compounds; this not only saves time, but also reduces the risk of incomplete disinfection resulting from a sterilization period that is too short.

After sanitization, the equipment is stored in a dry and dust-free place, where airborne contaminations are minimal and the equipment will dry quickly. Milk cans, pails and other containers must be stored upside down, to drain. It is advisable to disinfect the utensils again immediately before they are used.

Large farms may possess special steam or hot-air cabinets in which the utensils or parts of the equipment can be sterilized.

Milking machines

Milking machines require special care. The manufacturer's instructions for maintenance and sanitization must be followed punctiliously. There are several systems for sanitization; the principal ones will be discussed briefly below.

After a thorough rinse with cold or lukewarm water, the machine is cleaned manually by brushing all parts with a washing solution as described before, using a hard brush. A tapering conical brush is especially suitable for teat-cup liners; brushes on a long wire can be used for long milk tubes. Care should be taken not to damage rubber parts by using worn wire-stemmed brushes. Special cylindrical brushes may be used for the claw pieces. Washing troughs are especially suitable for cleaning the various parts of the equipment. They are left in the trough during cleaning in order to extend the time of contact with the washing solution, which is particularly useful if a combined detergent-disinfectant is used. A final rinse is given, to remove the washing solution. This rinse can be combined with the sterilization of the equipment. It is advisable to remove a corrosive disinfectant after chemical sterilization, especially if its concentration is high and it will take a long time to decompose. An excessively strong oxidizing effect of disinfectants will reduce the lifetime of the rubber parts.

Some advisors regard a less intensive sanitization programme, consisting of a thorough pre-rinse followed by a disinfectant rinse after the evening milking and a complete sanitization programme after the morning milking as being sufficient; however, such a programme increases the risk of poor-quality milk.

Repeated and intensive brushing with hard brushes may damage the rubber parts of the milking machine. Therefore, a flush system of cleaning has been introduced, consisting of a pre-rinse followed by drawing a washing solution through the system (clusters and bucket) for some time, after which the equipment is washed with plain water. Immediately before milking, a disinfectant is drawn through the system. It is recommended to clean the bucket-lid gaskets separately by hand before the flush cleaning starts. The mechanical procedure of sanitization has the advantage that stronger washing solutions at higher temperatures can be used.

In the systems described above the machine and its parts are stored 'dry' between milkings. The wet-storage cum sanitization of clusters is said to improve the results of sanitization and to prevent the development of microbes between milkings. Wet storage involves hanging the clusters in a special rack so that the teat cups and the milk tubes can be filled either with a very weak solution of an alkaline detergent or with a disinfectant (Figure 75). Great care must be taken to prevent corrosion by aggressive detergents and disinfectants. Wet storage should be regarded as an adjunct to normal sanitization.

To protect rubber parts of the equipment, which easily deteriorate by oxidation, the time of contact with oxidizing disinfectants such as hypochlorites should either be limited, for instance to 1 or 2 minutes for a solution containing 100 ppm active chlorine, or these disinfectants should be used in low concentrations (e.g. 10 ppm) only, as in the case of wet storage.

Milk tubes are made of natural or synthetic rubber, or from plastics. Natural rubber and, to a lesser extent, synthetic rubber, can absorb milk fat, resulting in a swelling and softening of the material. Defatting at intervals by immersing the rubber parts in a 5% caustic soda solution over longer periods of time may be useful. The fat diffuses to the surface, where it is saponified and can be scraped or brushed off.

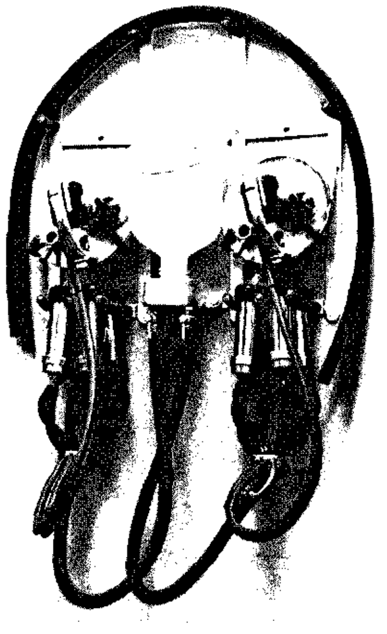

Fig. 75. Wet storage of clusters. *Photo: CMMB, Wageningen.*

Milkstone must be removed. This can be done as a routine daily treatment by a separate acid rinse, or by a special descaling procedure with a solution of phosphoric acid, whenever it appears necessary.

Circulation cleaning

For farms where pipeline-milking is applied, a recirculation system for sanitizing the milking plant has been introduced (the cleaning-in-place, or CIP system), whereby cleaning and sterilizing solutions are circulated through the plant in such a way that all surfaces that come into contact with the solutions are sufficiently sanitized. By immersing the clusters of the milking machine in the wash trough, the solution can be drawn through the entire plant. The solution may also be drawn from a special small tank. A closed recirculation circuit is obtained by returning the liquids along the vacuum or a special pipeline, or – what is often found most practical – along a loose plastic hose, which is connected solely for this purpose.

The cleaning and sterilizing liquids should not be applied before the whole plant has been thoroughly flushed with water to remove as much milk residue as possible. The sanitizing solution containing 0.5 to 1.5% caustic soda or another compound of comparable strength, should be circulated for 10 to 15 minutes, commencing at a temperature of about 70 °C or slightly higher. Loss of temperature, although unavoidable – especially if the circuit is a long one – should be minimized as much as possible. Preheating the plant with hot water reduces the temperature loss of the sanitizing solutions. If a detergent solution is used instead of a combined detergent-sterilizer solution, a sterilizer must be circulated through the plant after every washing.

Immediately after sanitization, the plant must be rinsed with clean water. Bacteriological results can be improved – if necessary – by replacing the water used for the after-rinse by a weak disinfectant, e.g. a chlorine solution of about 10 ppm; another weak chlorine rinse may be given immediately before milking. Sometimes, only the second rinse is given.

To prevent scale formation, an acid or an acid detergent should be circulated whenever necessary.

Farm-tank coolers

Farm-tank coolers on farms or collection centres must be rinsed with clean water immediately after emptying, and the cooling system must be switched off. Thereafter, sanitization can proceed. Farm tanks of the closed type are cleaned mechanically; tanks with a manhole with a removable lid can either be cleaned manually, or mechanically if the closure of the lid is constructed in such a way that no washing solutions can splash out.

In the process of manual cleaning, removable parts such as dipstick, agitator, thermometer and thermostat are removed to be soaked in a wash trough in a detergent-sterilizer solution. The temperature of this solution should be kept low (about 30 °C), if the thermometer and thermostat are not heat-resistant. The tank and its cover are thoroughly brushed with a detergent-sterilizer solution. The temperature should not exceed 40 °C. Cold washing solutions are used for the cleaning of tanks with an indirect cooling system, especially if the inner wall of the tanks is in contact with the ice water. Attention should be given to the tank outlet and its tap.

After the tank has been sanitized and the washing solution drained off, the removable parts are cleaned and rinsed with a disinfectant solution, and then reassembled. A final rinse with cold water, preferably a weak solution of a sterilizing agent, e.g. containing 10 ppm active chlorine, completes the sanitizing procedure; after this, the cooling system can be switched on again.

Mechanical cleaning is achieved by circulating the various liquids, which are sprayed in the tank with the aid of special spray-balls or spray-jets. To acquire the required pressure for efficient spray-cleaning, a special circulation pump is introduced in the system. The mechanical cleaning system may be hand-operated or be fully automated.

Sometimes, it is advisable to wash removable parts by hand, even though the tank has been cleaned mechanically.

Road and rail tankers

The same principles of cleaning as described for farm tanks can be used for road and rail tankers. If sanitization takes place on the premises of a dairy plant, steam will usually be available and sterilization may take place by heat treatment. After heat treatment, the man-hole should be left open to the air to prevent the walls of the tank from collapsing during cooling.

Insulated tanks take longer to reach the sterilization temperature, it will also take some time until the tanks have cooled enough to be used again for milk if a rise in the temperature of the milk is to be avoided. The temperature increase of the milk in the event of large tankers is practically negligible, but nevertheless, cold sanitization may be preferred.

13.3 Sanitization in collection centres and dairy plants

Sanitization in small centres and plants can be done manually by brushing the equipment with washing solutions and dismantling the pipeline-system for brushing with brushes on long wires. Sanitization must be accomplished in a similar way as described in the previous sections.

Modern plants are so designed that total sanitization can be done without dismantling pipelines and equipment such as separators, clarifiers, heat exchangers, storage and processing tanks, etc. This so-called cleaning-in-place (CIP) system is labour-saving and has proved to give better results than can be achieved by dismantling the installation daily. Subsequently, water for rinsing and washing and sterilizing solutions are circulated through the installation by a separate arrangement, consisting of pumps, detergent tanks, additional pipelines, etc. A CIP system can be completely automated.

Cleaning is achieved by the combined action of suitable detergents and mechanical force. In manual cleaning this force is achieved by the use of brushes; in mechanical cleaning it is achieved by violent turbulence in pipelines and equipment. This turbulence is brought about by a high speed of the solution. If the capacity of milk pumps is not high enough to reach this speed, separate pumps for sanitization are required.

In addition to the sanitization of pipelines and equipment that can be included in the CIP system, certain items need special sanitization programmes, for example, equipment used for making cheese and butter, and evaporators, milk drying plants, etc. Heat exchangers may have a separate circulation circuit.

Instructions for sanitization should be obtained from the manufacturers of the equipment, or from specialized handbooks. Only the cleaning of milk cans and bottles will be discussed briefly below.

Milk cans

Poorly sanitized milk cans – even if they appear clean to the eye – are among the major causes of milk contamination. Since dairy plants are often not in a position to control sanitization of the cans on farm level, it is best to clean the cans at the collection centre or the dairy plant. Small centres or plants that are unable to set up a can-washing unit may provide the milk suppliers with facilities for cleaning their cans at the place of milk delivery. Such facilities may consist of troughs with washing solutions, brushes, clean water, etc. Larger centres and plants should consider the possibility of installing a straight-line or a rotary can washer (Section 5.1).

Straight-line can washers

After emptying, the cans are put upside-down on a draining rack. The draining rack is coupled to a straight-line can washer, where the cans pass over a number of nozzles from which they are successively squirted with water and detergents at appropriate temperatures (see rotary can washers). Ideally, before leaving the can washer, the cans are sterilized by means of steam injection, and dried with hot air. The lids are cleaned together with the cans. After passing through the can washer the cans are automatically turned right-side up and the lids replaced. The empty cans pass over a second conveyor to the platform, where they are picked up by the collection vehicle.

Rotary can washers

Instead of the straight-line can washer, a rotary washer is sometimes preferred for smaller capacities, i.e. up to 6 or 7 cans per minute. These washers are characterized by a rotating platform on which 6 or 7 compartments are constructed; each compartment can contain one can. The compartments rotate intermittently. During the stationary period, the cans are situated over jets through which the washing solutions are squirted into the inverted cans. The washing solution, containing about 0.3% caustic soda, should have a temperature of at least 70 °C. After sanitizing, the cans are rinsed with hot water and finally steamed or dried with hot air. In some washers an additional squirt with an acid solution is given after the treatment with an alkaline detergent. Manual labour is required to load and unload the washer. This is done during the stationary period, when there is free access to one compartment.

Milk bottles

It is essential that bottles be washed and sterilized efficiently, to safeguard the quality of the milk and to nullify infections coming from the various households. A bacteriologically unsatisfactory condition of the washed bottles is often responsible for a poor keeping quality of the milk. Bottles containing residues of sour or dried milk or milk products may be difficult to clean. Automatic cleaning systems must be adjusted to cope with the dirtiest bottles. Bottles that have been used to store products with a strong odour or flavour (e.g. kerosene or paint), must be rejected before washing, because they cannot be made odourless and they may contaminate the cleaning solution. Such bottles must be sorted out; this necessitates inspecting all bottles before cleaning.

Manual washing

The manual washing of bottles is only justified in very small plants. It is very labour intensive and the quality of cleaning is difficult to control. In manual washing, either a hand brush, or a motor-driven brush is used. The detergent may not be too strong, otherwise it will be injurious to the operator's hands. Therefore, a mild alkaline solution is used at moderate temperatures. It is advisable to soak the bottles for at least several minutes before cleaning them. After cleaning, the bottles are put in clean warm water to remove the adhering detergent. This water must be refreshed regularly. After

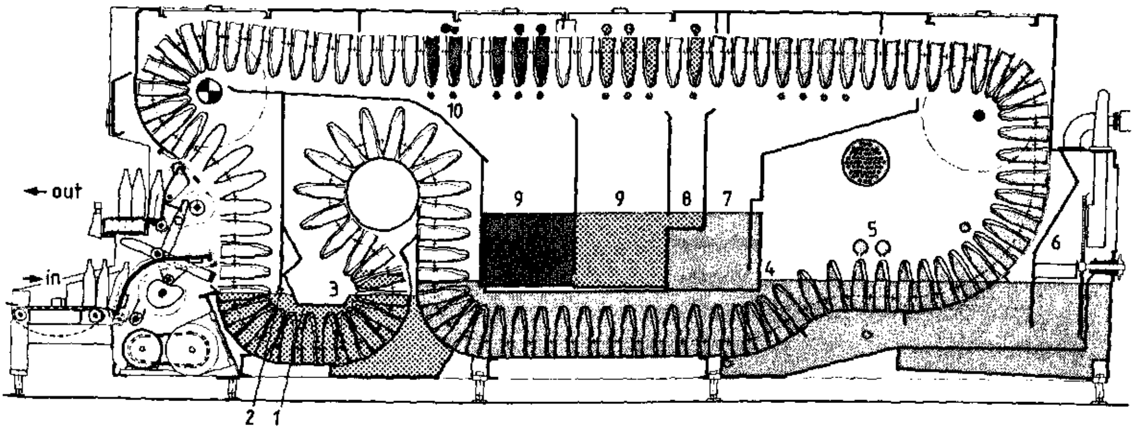

Fig. 76. *Soaker-type bottle washer.* Dirty bottles are loaded into bottle holders which are mounted in rows on an endless conveyor which moves the bottles through soaking baths and over spray jets. The spray jets squirt the bottles with solutions of detergents and with water. The cleaned bottles are discharged from the washer at the same side as loading takes place. 1. Pre-soak bath. 2. Extraction of contaminated air from the bottles. 3. Emptying residue. 4. Detergent soaking bath. 5. Label spray section. 6. Label discharge. 7. Detergent spray section. 8. Intermediate spray. 9. Water spray section. 10. Fresh-water spray section. Courtesy: Stork Amsterdam B.V.

rinsing, the bottles are kept in a cold chlorine solution (100 to 200 ppm) for some time. After cleaning and sterilization the bottles are left upside down in cleaned crates until they are filled again.

Machine washing

Although rotary bottle washers are used for small capacities, nowadays, automatic straight-line bottle washers are generally used. The rotary washers are loaded and unloaded manually. The straight-line washers may be loaded by hand or automatically, unloading is generally mechanized.

Automatic bottle washers are either jet-type washers or soaker-type washers. In the former type – to which all rotary washers belong – the bottles are sprayed with water and washing solutions from a series of jets for washing and sterilization. In the soaker-type washers, the bottles are carried through one or two strong alkaline soaker solutions prior to jet-washing and sterilization (Figure 76). The bottles may be rinsed before they enter the soaker-bath.

Some automatic washers are equipped with automatically operating brushers.

The bottles travel through the washer in receptacles constructed on an endless apron, which moves through the machine and carries the bottles through the various treatments.

The detergents used in bottle washers usually consist of caustic soda with a number of additives, such as emulsifiers, wetting agents, etc. The strength of the solutions and their temperature depends on the system of the washer. The concentration of the detergent solutions should be inspected at regular intervals.

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*In composite terms, the word 'milk' is often deleted, e.g. 'milk fat' and 'milk collection' are indexed under the terms 'fat' and 'collection', respectively. Special mention is only made of buffalo's, sheep's, goat's and camel's milk, not of milk in general nor cow's milk.