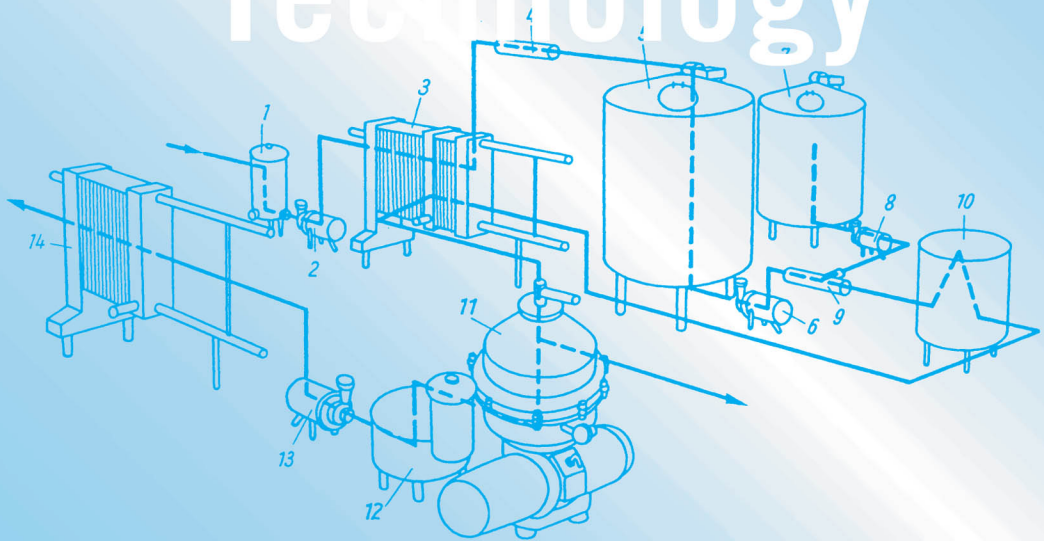


Milk and Dairy Product Technology



Edgar Spreer

Milk and Dairy Product Technology

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Preface

For more than 25 years it has been the purpose of this book to convey basic knowledge of milk processing in a concise form to a broad spectrum of interested persons. In view of the needs of the readers, it has become necessary to publish a seventh edition. This edition has been reedited very thoroughly; major new scientific findings, experiences and amendments—especially with regard to the legal conditions of the European Union—have been added; and some chapters have been shortened. Major chapters deal with (apart from the key raw material milk) technological subjects related to the production of milk-based products and quality assurance. Other chapters deal with additives, replacers, auxiliary processes and subprocesses, as well as cleaning and disinfection and water and energy use in a dairy. Chemistry, physics and microbiology of milk and milk products as well as analytical methods are dealt with to the extent necessary for understanding the technology. Dairy-economical calculations have been drastically reduced, as another publication, “Calculations in the Milk Industry,” is closely linked with this book and with each individual subject.

This book is intended to help the readers to understand and control the complex production processes in a dairy plant from a theoretical point of view, especially apprentices and students beginning their career in the dairy industry. For practical-minded professionals it will serve as a reference; for teachers and trainers it is intended to serve as a support in their profession.

It is a pleasure to thank all those who have supported the progress of this publication in an active way: above all, the publishing house for excellent cooperation; all the associates of the association Zentralverband Deutscher Milchwirtschaftler e.V. and the Verband der Deutschen Milchwirtschaft e.V.; the companies and institutions who contributed by providing pictures for this book; and colleagues in the information processing section of the Sächsische Staatsministerium für Landwirtschaft, Ernährung und Forsten.

My special thanks go to Dr. Carl-Ludwig Riedel, Krefeld, a knowledgeable expert on dairy literature, who helped the author with a multitude of ideas and suggestions in order to update this book.

I would like to ask all readers for a critical review and suggestions for additional improvement of this book.

Edgar Spreer

About the Translator

AXEL MIXA is a food technology consultant based in Norderstedt, Germany. He has wide international experience in both the technical and managerial aspects of dairy product manufacturing and is a member of the Institute of Food Technologists. Mr. Mixa received the M.S. degree (1973) in food technology from the Technical University of Berlin, Germany.

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1 Introduction to Technology

1.1. Basic technological terms

1.2. Dairy technology

1.3. Dairy plants

1.4. Professional requirements



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1 Introduction to Technology

1.1. Basic technological terms

Processing milk into a wide variety of products requires a highly developed technology, for which we use the following definition:

- Technology is the science and the application of scientific, economic, as well as sociological, knowledge and legal rules for the production of raw materials and their further processing into semifinished and finished goods.

Technology reflects the relationship between the object, the means and the labor in a process, as well as the individual unit operations in the production process.

During the development of a technology into an independent branch of science, a further categorization takes place. We distinguish between the technology of material processing (mechanical technology) and the technology of material conversion (chemical and biological technology). Specialized areas have been developed, e.g., biotechnology and food technology, wherein you can find dairy technology.

In a further categorization of technology we find the production processes.

- Descriptions of the processes include how raw materials—as a function of their class, characteristics and composition—are modified and changed by processes and result in finished goods.
- Process technology deals with the technical-industrial implementation of processes.

Process technology deals mainly with aspects of raw material conversion, i.e., the inner structure and state of materials. Manufacturing technology deals with the change of raw materials in regard to form, shape and localization.

For a proper description of these technological processes, unit operations are used, which can be subdivided (see Overview 1./1). According to Raeuber,¹ the following definition is used:

- Technological unit operations are operations, which are independent of special raw materials of the processes, proceed according to identical rules and can be repeated with identical technical equipment.

Flowsheets are used to describe the processes in a graphical form. They can describe the processes and material modification in a qualitative way or the material quantities in a quantitative way; they can also show the equipment, installations, vessels and complete piping diagrams.

Colloquially, these process sequences, consisting of processes and subprocesses in a certain sequence, may be referred to as processes or technology.

¹ Raeuber, H.-J.: Die Technologischen Grundverfahren und ihre Systematik. Die Lebensmittelindustrie 8 (1961), No. 9, p. 279.

Overview 1./1 Technological Processes (Selection)

Modification of Energy	Modification of Composition			Modification of Space	Modification of Form
	Reaction Process	Combining Process	Separation Process		
Tempering	Chemical Peeling Cooking Brewing Pasteurization Sterilization Ripening Acidification	Dusting Humidifying Emulsifying Kneading Colloid milling Solubilization Mixing Rehydration Suspension Immersion Blending	Absorption Pressing Gravity sorting Color sorting Filtration Shape sorting Picking Vacuum separation Sedimentation Sieving Sifting Drying	Breaking up Compressing	Breaking Milling Tearing Cutting Grinding Form pressing Granulation

Equipment, machinery, instruments, vessels and installations—used for the realization of the processes—are put under the heading “technique,” wherein you commonly find subjects like instrument technology, installation technology or other technical installations. In the narrower scientific description, “technique” is the key subject, from which all other subjects of engineering are derived.

1.2. Dairy technology

Applying the general definition of technology from Section 1.1, we may define dairy technology as a combination of theoretical and practical knowledge based on a scientific background and the control of processes for the treatment and conversion of milk into milk products.

During the development of dairy technology, the following classical milk product groups and technologies have been developed: market milk (fluid milk), acidified milk products, butter, cheese and long-shelf-life products, which characterize milk processing. Figure 1./1 shows a basic flowsheet for the most important technologies.

With the increasing variety of milk products, as well as the innovations in machinery and plant design, the basic technologies for dairy processing are being constantly modified.

The movement toward electronic data processing, modern separation techniques (like ultrafiltration, reverse osmosis or electrodialysis), aseptic filling technology or biotechnology, and the constantly changing consumer requirements with regard to product quality and safety are controlling the development of the dairy industry. We see the following trends:

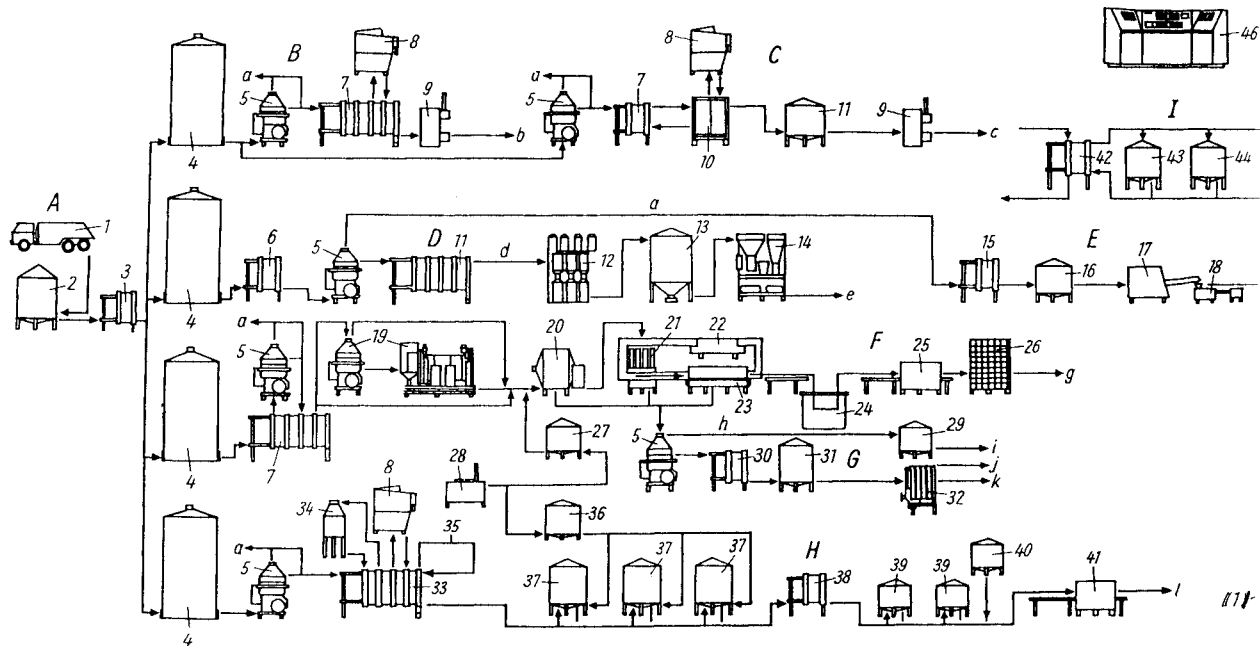


Figure 1.1 Flowsheet of basic processes in dairy technology

(A) Milk reception (B) Fresh Milk production (C) Sterile Milk production (D) Milk powder production (E) Butter production (F) Cheese production (G) Whey utilization (H) Yogurt production (I) CIP plant.

(a) Cream (b) Fresh Milk (c) Sterile milk (d) Skim milk (e) Milk powder (f) Butter (g) Cheese (h) Whey (i) Fat (j) Protein (k) Concentrate of milk components after filtration (l) Yogurt.

(1) Milk transport tank (2) Quantity determination (3) Raw milk chiller (4) Raw milk silo (5) Separator (6) Preheater (7) Plate heat exchanger for heat treatment (8) Homogenizer (9) Filling line (10) Sterilizer (11) Sterile tank (12) Evaporator (13) Spray drier (14) Powder filling line (15) Cream heating (16) Cream incubator (17) Butter machine (18) Butter packing line (19) Bactofugation line (20) Cheese maker (21) Cheese washing installation (22) Cheese washing installation (23) Cheese press (24) Brine installation (25) Cheese coating device (26) Cheese storage (27) Tank for starter culture (28) Tank for intermediary culture (29) Cream whey tank (30) Plate heat exchanger (31) Whey tank (32) Ultrafiltration line (33) Yogurt plate heat exchanger (34) Deaerator (35) Holding section (36) Yogurt starter tank (37) Incubation tank (38) Yogurt chilling section (39) Semifinished product tank (40) Tank for fruit ingredients (41) Yogurt filling line (42) Plate heat exchanger (43) Acid tank (44) Lye tank (45) Rinsing water tank (46) Control panel.

1. Systematic quality assurance for products and processes with corresponding certification and reinforced orientation toward brand products.
2. Loss-reduced or totally loss-free utilization of all milk components with further fine-tuning, e.g., improved whey utilization.
3. Replacement of individual dairy components by other foods (vegetable proteins, animal and vegetable fats); manufacture of imitations and substituted products.
4. Increased utilization of computer technology for data capture and process control, raising the level of automation.
5. Modification of packaging systems and materials for multiple use or recycling.
6. Application of biotechnology for the optimization of fermentation processes, use of enzymes for the acceleration of subprocesses (cheese ripening) and application of gene technology for microorganisms to promote reliable chemical reactions and increased resistance to harmful influences.

Apart from these trends in industrialized countries, special emphasis needs to be given to the dairy industry in developing countries. In order to increase the production volumes of milk products, the following aspects need to be considered for process control:

- a) Climatic conditions
- b) Quality of the milk to be processed in the context of health, nutritional status and the type of dairy animals
- c) Distribution and marketing of the products
- d) Training and competence of the personnel

1.3. Dairy plants

The implementation of dairy technology occurs in dairies and milk processing plants. In colloquial language, these terms are synonymous. The definitions and standards used in milk regulations also apply to the regulations for cheese and other dairy products.

- Dairy plants (dairies) manufacture milk products from milk, for which they use building installations of one or several plants having manufacturing, auxiliary and support sections.
- Milk processing plants are part of a dairy company, which consists of all manufacturing sections used for milk treatment and processing, beginning with milk reception and ending with the dispatch of the finished products. They operate within the framework of the milk regulations and consist of a production program and regulations, flowsheets, energy flowsheets and functional descriptions.
- Small dairies and cheese plants are installations that have a daily average volume of at least 500 l of milk (or corresponding products derived from this quantity) on an annual basis and have the required technical installations.

Production installations implement processes (see Section 1.1) in order to convert raw material of a certain quality into products of a prescribed quality. The following tasks are performed by production installations:

1. Preparing and making raw materials available
2. Treating and processing raw materials according to defined processes
3. Accepting semifinished products, byproducts and finished products

The implementation of these processes requires installations consisting of machines, instruments and vessels (see also 4.1) that are sequenced according to the process and are linked by suitable transport facilities and pipelines. The corresponding instruments are required for process control.

Auxiliary installations are part of a dairy plant. They have only an indirect influence on the manufacturing side but are indispensable. They consist of:

1. Energy supply installations for electricity, heat, refrigeration and compressed air (see Chapters 13 to 15)
2. Water supply and wastewater installations (see Chapter 12)
3. Auxiliary materials
4. Laboratories for the control of raw materials and intermediate and finished products as well as pilot plants for research and development of new processes
5. Factory-internal transport conveyances and devices

Storage of raw material and finished goods is allocated to the production facilities.

Auxiliary installations include administration and office buildings, personnel facilities, engineering facilities for the repair and testing of machines and equipment, garages, cleaning installations, roads and parking facilities.

1.4. Professional requirements

Dairy professionals are responsible for the following tasks related to the complex processes in a dairy:

- Control of the chemical, physical and microbiological processes during the processing and treatment of milk into dairy products.
- Proper packaging, storage and transport of the finished goods.
- Operating, maintaining and servicing the machinery and equipment.
- Production and Quality Control of the products.
- Compliance with hygiene and workplace safety regulations.

In order to deal with all these tasks, apprentices have to make great efforts in their practical and theoretical training. Acquisition of this knowledge and experience and qualities such as exactness, industriousness, punctuality and reliability are basic requirements for the professionals who control the processes in dairy plants.



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2 Milk as a Raw Material and Food

2.1. Terms

2.2. Milk as a food

2.3. Composition and characteristics of milk

2.4. Microbiology of milk

2.5. Cell count of milk

2.6. Quality assurance

2.7. Raw milk



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2 Milk as a Raw Material and Food

2.1. Terms

Milk is the liquid, excreted by the mammary glands of both humans (women) and mammals, which is serving the newborn as food. Within the context of dairy technology, the following definition can be used:

- Milk is the product obtained by simple or multiple milking of mammals that are kept for the purpose of milk production.

In the majority of cases, this term is used for cow's milk, which is produced as a raw material in agricultural institutions and is treated in dairies (see also 2.7). Milk of other kinds of animals kept for milk production is labeled specifically (goat milk, sheep milk, buffalo milk and others), and the quality requirements are similar to those for cow's milk.

Apart from the milk proper, a variety of products based on milk are of importance for feeding humans and animals. Milk-based products can be divided into milk products and recombined milk products.

- Milk products are made entirely from milk. In certain cases, additives can be used during the manufacture, but they cannot replace milk components either partially or completely.
- Recombined milk products are products in which milk or milk components constitute are major part. Milk components cannot be replaced by additives.

2.2. Milk as a food

Milk is one of the most precious natural materials and has been a basic component of human food for a long time. It is one of the oldest foods and at the same time the most important one.

- Food is a material destined to satisfy nutritional requirements and is consumed by humans in a modified, prepared or treated form through eating, drinking or intake in any other form.

Food is also the generic term for foodstuff or drugs, and a clear distinction between these two terms remains difficult.

Food is generally considered to be derived from materials or mixture of materials from plants or animals that are necessary to guarantee the growth, maintenance and functionality of the human organism.

Foodstuffs and drugs are foods derived mostly from plant material, whose nutritional value is low and without importance. Their consumption causes some pleasant sensations by stimulating the nerves.

In all developed countries, foods have been described in a legal fashion and have been controlled by these legal terms. A further fine-tuning can be found in the Codex Alimentarius. This is a description, in addition to the local legislation, which is ex-

tensive, exhaustive and factual and relates to the normal terms of trade and usage for both manufacturers and consumers.

The United Nations (UN) has issued—through its relevant organizations, e.g., the World Health Organization (WHO) and the Food and Agricultural Organization (FAO)—recommendations which have been adopted in many cases through local legislation. For milk and dairy products, standards have been developed by the International Dairy Federation IDF which are in use in many countries. The standards of the European Union (EU) have been adopted by its member countries in their local legislation.

The food needed for the development and maintenance of the human body as well as to meet energy requirements is covered by such basic nutritional components as fats, proteins and carbohydrates and reagents such as minerals, trace elements, vitamins and water.

Food also contains flavors and aromas, colorants, low-digestible crude fibers (which control the digestion) and antimicrobial substances. Food can even contain nondesirable, nutritionally negative or even poisonous substances (e.g., alkaloids or microbially derived toxins and/or harmful metabolic products) and microorganisms. Water, which is consumed directly or as a part of food or is in contact with food, is also considered a food.

In many cases foods cannot be consumed in their raw form (exceptions are fruits and vegetables). They need to be prepared in order to be consumed and digested by humans. At the same time, the spoilage of foods by microorganisms and enzymes is prevented.

During treatment, the chemical and physical modifications can reach such levels that the raw material is distinctly different to the finished product. In many cases, the non-desirable parts are to be removed or an enrichment or reduction of the nutritional content (and thus a change in the energy content) takes place.

The basic energy unit used to describe food is the joule (J) or kilojoule (kJ) according to the international standard units. The energy content is expressed as J/g or kJ/kg. Very often we still find old units such as calories (cal) or kilocalories (kcal) (1 kcal = 4.1868 kJ), especially for food whose energy content has been reduced. The term “reduced-calorie” or “low-calorie” is common. As these are terms which are part of normal verbal communications and the consumers are used to them. Milk is a complete food for the human nutrition. It contains all the basic components and reagents which are required for the development and maintenance of human life. It should be noted that the protein value of cow’s milk, i.e., the ratio of protein energy to the total energy of milk is 20% more favorable than for all other foods (exception breast milk). For an overview of the energy content of milk and other animal-based foods see Table 2./1.

One liter of milk supplies the following daily requirements for the human being:

Calcium	100%	Vitamin A	30%
Phosphorus	67%	Vitamin B ₁	27%
Vitamin B ₂	66%	Vitamin C	19%
Protein	49%	Iron	3%

- One liter supplies about 20% of the daily energy requirements for the human being.

2.3. Composition and characteristics of milk

Milk is a white, opaque liquid; it can be slightly yellowish, especially during the summer when the cows are out in the meadows. It is supposed to have a typical, clean,

full, slightly sweet taste and should also have a typical clean smell. The consistency (see also 2.3.2) is homogeneous, without clot formation or flocculation.

Table 2./1 Energy content of milk and dairy products in comparison to other food

Food type	Energy content	
	Average values	
	In kJ	In kcal
Whole milk 3% fat	2900	690
Skim milk	1600	380
Butter 80% fat	33500	8000
Cheese (Tilsit) 45% fat in dry basis	16750	4000
Quarg 40% fat on dry basis	8800	2100
Beef, lean	5850	1400
Pork, lean	10500	2500
Eggs	7100	1700
Herring	10425	2490

From a chemical-physical point of view, milk consists of several different components, also called fractions, phases and components.

- Fractions are groups which can be separated sequentially (fats, proteins, carbohydrates, salts).
- Phases are homogeneous ingredients in a nonhomogeneous dispersed system, which can be separated by physical means (separation, filtration, evaporation).

In the polydisperse system milk (see also 2.3.2.2) we find a fatty phase and a fat-free aqueous phase during the centrifugal separation.

- Components are the chemically distinct parts of a fraction or phase.
- The protein fraction of milk consists of several such components, which can be separated chemically. Composition and organoleptic characteristics of milk are changing significantly during the lactation period (300 days), which is the time when the cow yields milk (Figure 2./1). The milk which the cows give within the first 7 days after calving is called colostrum milk or colostrum. Colostrum can be found within 10–14 days, and sometimes even after 3–5 weeks characteristics of colostrum milk can be found. Colostrum milk within the first 6 days is not accepted by the dairies.

Colostrum milk has a salty taste, is slightly gluey, has a yellow to brownish color and is subject to flocculation during boiling. The specific density is in the range 1.033–1.094 g/cm³ and the SH (Sohxhlet-Henkel) value (titrable acidity; see also 2.3.2.5 and Table 2./7) is 10 to 15. At the end of the lactation period, i.e., a few weeks before the new calving, the milk returns to a colostrum character. Dry matter increases, the fat globules have a smaller diameter and the enzymatic precipitation characteristics deteriorate. Such a milk is difficult to convert into cheese.

Milk from the middle period of the lactation—in its natural composition and characteristics—is the most suitable raw material for the manufacture of high-quality dairy products. Table 2./2 shows the average composition of this milk compared to breast milk and milk from other animals.

Significant variations from the average values can be observed. These are influenced by the stock and the particularities of the cows, feeding, maintenance, lactation period as well as health and age of the animals.

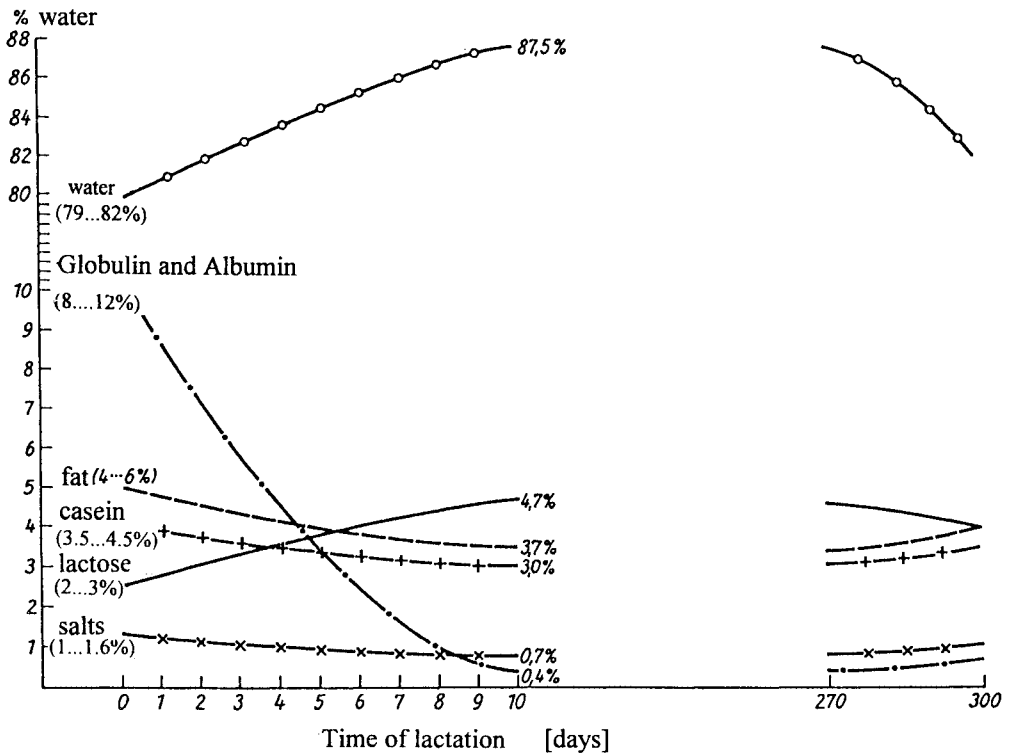
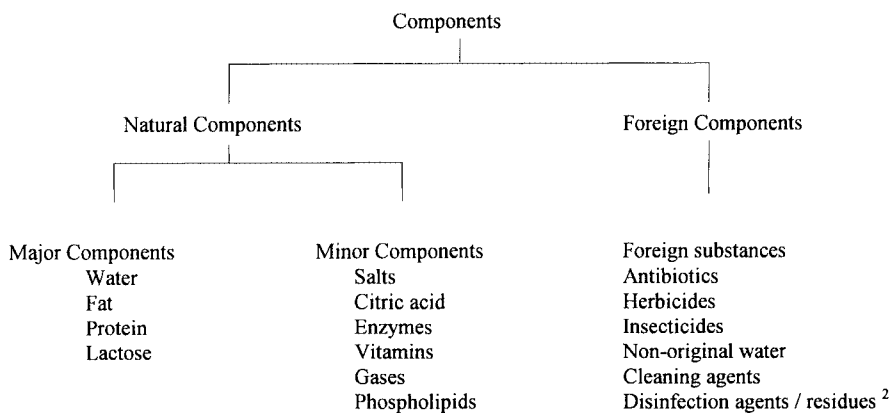


Figure 2./1 Changes in milk composition during the lactation period

Overview 2./1 Components of milk



² By contamination during milking and processing

2.3.1. Chemical composition

The basic components of milk are shown in Table 2./1. The original components are

retained in the milk, i.e., developed through the metabolic cycle. Fatty substances e.g., phospholipids (phosphatides), are substances which contain phosphoric acid as an esteric component. Foreign substances are found in milk due to contamination (blending or contamination with other material) from the environment via plants, veterinary hygienic activities or the treatment process. Antibiotics are metabolic products of microorganisms which inhibit the development of other microorganisms. Herbicides are substances for weed control, insecticides are substances for insect control (see also 2.3.1.9).

Breast milk is different in its composition from cow's milk. It has a higher lactose content (7.9%) and a significantly lower protein content (1.0%), of which casein is barely 50%. The majority of the protein is from albumin. Nonadapted cow's milk can lead to serious digestive problems in newly born babies. The feeding of babies and small children has been optimized, and the infant sickness rates and fatality rates have been reduced, by the continuous progress in the development of adapted infant milk.

Table 2./2 Average composition of breast milk, cow's milk and milk from other animals¹

	Dry Matter [%]	Fat [%]	Total Protein [%]	Casein [%]	Whey Protein [%]	Lactose [%]	Ash [%]
Human	12.4	3.8	1.0	0.4	0.6	7.0	0.2
Cow	13.0	4.0	3.4	2.8	0.6	4.8	0.7
Goat	13.2	4.5	2.9	2.5	0.4	4.1	0.8
Sheep	19.3	7.3	5.5	4.6	0.9	4.8	1.0
Donkey	8.5	0.6	1.4	0.7	0.7	6.1	0.4
Horse	11.2	1.9	2.5	1.3	1.2	6.2	0.5
Buffalo	17.2	7.4	3.6	-	-	5.5	0.8
Camel	13.6	4.5	3.6	2.7	0.9	5.0	0.7
Lama	16.2	2.4	7.3	6.2	1.1	6.0	-
Yak	17.3	6.5	5.8	-	-	4.6	0.9
Elk	21.5	10.0	8.4	-	-	3.8	1.5
Reindeer	33.1	16.9	11.5	-	-	2.8	-

¹ See Kielwein, G.: Leitfaden der Milchkunde und Milchhygiene, Berlin und Hamburg: Verlag Paul Parey, 1976

2.3.1.1. Water

Water is the major component of milk and is used principally as a solvent for the ingredients. In dairy products e.g., butter, cheese, milk powder, we also find in the form of chemically bound water, e.g., as hydrated water in protein or bound in lactose crystals, or as freely available moisture in products.

The sorption of the water by its various substances can be explained as follows:

- a) Sorption with a chemical reaction
- b) Sorption with formation of hydrates
- c) Adsorption with surface energy
- d) Diffusion of water molecules into the structure
- e) Capillary condensation
- f) Development of a solution

Several of these activities can happen at the same time. The water content influences above all the texture (see 2.3.2.1) and the physical and mechanical properties of the food.

- The water (moisture) content in % H₂O is the quantity of water in the product related to its dry matter.

Preservation, i.e., the microbial stability, is controlled by the freely available water. This part is termed water activity.

- Water activity or moisture isotherm, expressed as the a_w value represents the free part of the available water in a hygroscopic material.

In a simplification, the water activity can be defined as the ration of the steam pressure p of the water on the surface of the food to the steam pressure p_0 of pure water at the same temperature.

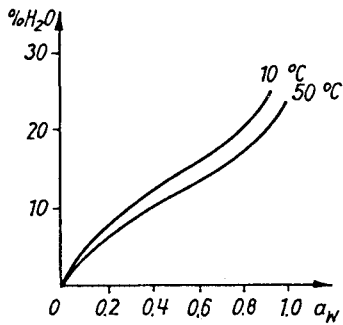


Figure 2./2 Sorption isotherms

$$a_w = \frac{p}{p_0}$$

When a substance is in hygroscopic balance with the environment, water activity and relative moisture φ are related. Both terms are identical in values, and the water activity is 1/100 of the relative humidity.

$$a_w = \frac{\varphi}{100 \cdot \varphi}$$

In a balanced state the relationship of % H₂O and a_w can be shown by a graphical curve, the so-called sorption isotherm.¹ For each a_w value, the sorption isotherm shows a corresponding % moisture value at a given constant temperature (Figure 2./2). Due to the complexity of the sorption characteristics, they cannot always be predicted and need to be determined experimentally. It is therefore advantageous in many cases to determine the water activity with suitable devices. The determination of sorption isotherms is of great significance, especially during drying.

Foods high in moisture have an a_w of 0.9–1.0, semimoist foods range from 0.6 to 0.8, and dry foods have a range of 0–0.5. Bacteria need an $a_w > 0.85$ for growth and metabolism; some yeast and molds need an $a_w > 0.75$. Enzymatic reactions are slowed down with an $a_w < 0.8$, but can still take place at $a_w = 0.3$. The optimum for chemical reactions (for

¹ Sorption: Intake of gases, vapors or other soluble substances into another substance.

Absorption: Penetration of a substance into the entire volume of another substance.

Adsorption: Bonding of gases or liquids to the surface of a substance.

nonenzymatic browning or Maillard reaction) is $a_w = 0.6-0.7$; for fat oxidation requires an $a_w < 0.3$.

The water activity strongly influences the drying process, i.e. the energy required for drying of a product. With pure water (or an $a_w = 1.0$), the drying or evaporation enthalpy is 2300–2500 kJ/kg. With a reduced a_w value, the drying enthalpy increases drastically, and it reaches 4000–5000 kJ/kg at an a_w level of 0.1.

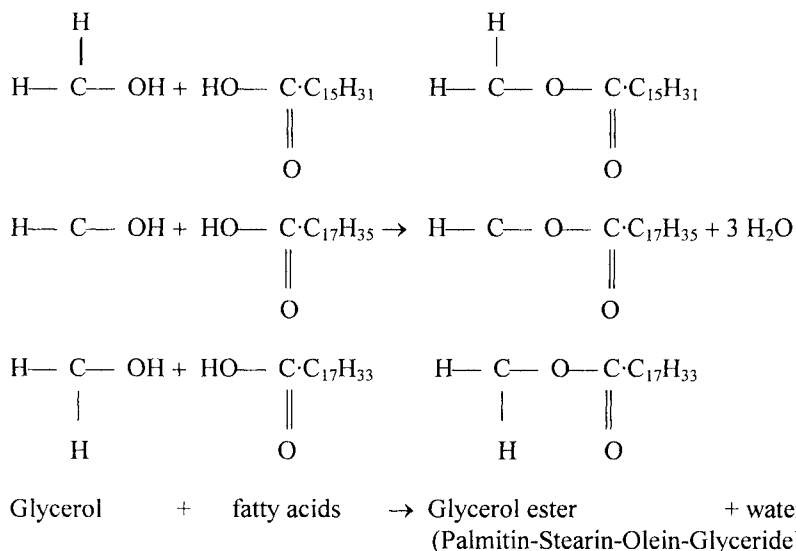
2.3.1.2. Milk fat

Of all the components, the fat varies the most (from 3.2% to 6.0%). This variation is due to the breeding of the different types of cows. In addition, feeding, maintenance and health as well as the specific characteristics of the milk animals play a role.

Table 2./3 Characteristics for milk (butter) fat

Melting range	[°C]	28-40 (38 °C clear melting point)
Solidification range	[°C]	15-25
Refraction index at 25 °C		39.4-46
Iodine number		25-46
Saponification		218-235
Reichert-Meissl number		24-34
Polenske number		1.5-5

Fat is found in milk in form of spheres or droplets with a diameter of 2–5 μm , consisting of a fat core enclosed by a membrane. Milk fat is a simple lipid and consists of triglycerides, the esters of the trivalent alcohol glycerol (propanetriol) and the fatty acids (mono-carboxylic acids). Below is an example of a mixed triglyceride:



More than 400 fatty acids have been found in milk fat, of which only 10 determine the physical characteristics. Among them are the short-chain fatty acids C4, C6, C8, C10 and C12, as well as the long-chain fatty acids C14, C16, C18, C18:1(cis) and C18:1(trans). The long-chain fatty acids exist in both the saturated and the unsaturated state.

The ratio of saturated to unsaturated fatty acids is influenced mainly by feeding; in the summer the ratio of unsaturated ones is higher than during winter; therefore some specific values of the fat vary.

Milkfat melts over a wide temperature range. At temperatures $> 40\text{ }^{\circ}\text{C}$ it is liquid; at temperatures $< 40\text{ }^{\circ}\text{C}$ milkfat contains both liquid and solid parts. The dominant part depends on the ambient or cooling temperature. The wide melting range is due to differing compositions. Some physical facts of milkfat are shown in Table 2./3.

Knowledge of the composition of the triglycerides is of practical importance especially during butter manufacture, as this is how the consistency of butter is controlled. Of all the animal fats, especially body fats, milkfat is different because of the multitude of fatty acids and the higher ratio of unsaturated ones.

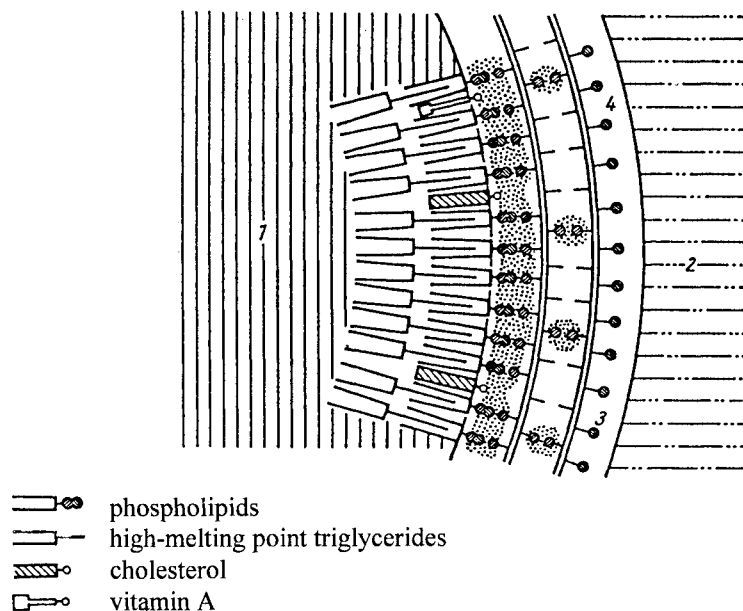


Figure 2./3 Structure of a fat globule (according to King)

(1) Fat (2) plasma (3) protein (4) zone of bound water

The membrane (Figure 2./3) is a multilayered chemical complex. The closest layer to the core consists of high-melting triglycerides, which project into the phospholipid layer. The phospholipids consist mostly of lecithin, which is said to have a positive effect on the nervous system; we find 0.1–0.3% in buttermilk and kephalin. But we also find vitamin A and cholesterol in the organic complexes of stearins, which have hydrophilic groups and form a bond with the next hydrate sphere. The phosphate layer is enclosed by the membrane protein, which is similar in structure to the globulin (see also 2.3.1.3) and contains as a special form, called euglobulin.

The membrane protein, including the bound water in the hydrate spheres, has a significant influence on the dispersibility of the fats in milk. Incorporated into the aqueous phase—oriented towards the milk—are enzymes, e.g., phosphatase (see Overview 2./3), heavy metals and salts. Finally, on the surface of the sphere is the electrical charge, which causes movement of the fat globule in an electrical field. This charge depends upon the pH value and is negative with a higher pH, and positive with a lower pH. The charge con-

version takes place at the isoelectric point of the sphere protein, which has a pH value of 4.1 to 4.5 according to King.

A detailed knowledge of the sphere structure is important, as this might influence the technology. Creaming of fat and butter formation are influenced very strongly by this.

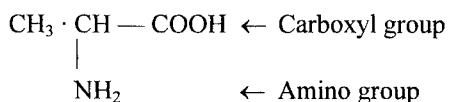
Fat damages. Mechanical treatment can have a very negative influence on milkfat. On the one hand, this is due to flow dynamics in pipelines and pumps and is inevitable during the production process. On the other hand, these influences are controlled in order to achieve changes of state such as a rapid change in the distribution state during centrifugal de-creaming and in buttering facilities (butter formation) as well as the stabilization of the distribution state (mixing, homogenization).

Negative influences (turbulence, shear) and the inclusion of air can cause strong degradation of the membrane, and separation of free fat from the fat globules can take place. Free fat is then attacked by the natural milk enzyme lipase, which then causes fat degradation and quality reduction of fat-containing products. Further the free fat is more strongly attached to the walls of the containers and it is more difficult to separate during de-creaming, causing fat losses.

- Raw milk and raw cream should be subjected to the lowest possible mechanical stress in order to avoid degradation of the fat globule.

2.3.1.3. Milk proteins

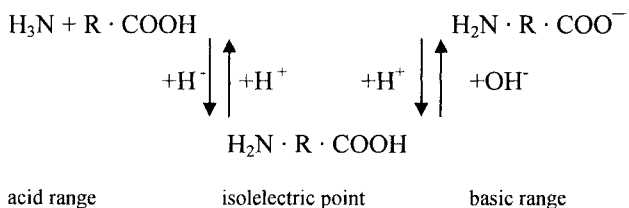
The basic components of proteins are amino acids. They are formed by different types of binding (peptide, disulfide, hydrogen bridges and ion binding) into specific structures and into polypeptides, and these are then formed into proteins. Amino acids are organic acids, which have an $-\text{NH}_2$ (amino) group and a carboxylic end. For example,



Alanine (α -aminopropionic acid; 2-aminopropionic acid)

The NH_2 group can usually be found on the second C atom; therefore the term α -amino acids is used. We know of about 50 different amino acids, of which 9 are essential, i.e., are indispensable for the human nutrition, as they cannot be formed by human metabolism.

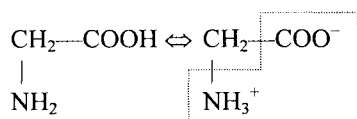
Protein molecules have an electrical charge, which depends on the pH value of the solution. The charge can be positive or negative, depending on the availability of free amino groups or carboxylic groups. As long as the protein particles exist in the form of cations (in the acid range) or anions (in the basic range), they can move in an electric field or can repel each other if they are equally charged. Therefore they remain in a soluble form.



At the isoelectric point, the same level of charge exists in the interior of the molecule.

- The isoelectric point is the pH value, at which dissociated chemical substances with acidic and basic groups in the molecules have the same level of charge; i.e., the number of positively charged ions is equal to the number of negatively charged ions.

Compounds such as the amino acids, which can dissociate into basic and acidic groups, are called ampholytes and cannot move in an electrical field. For example,



Glycocoll (aminoethanoic acid)

With equality of charge, the protein molecules tend to form inner salts with acids or lye, and we observe precipitation of the protein.

The classification of the proteins is not always uniform, as more and more knowledge on the finer structures has resulted in different classifications. According to Rapoport, the following definition can be used:

- Proteins are macromolecular compounds, made of α -amino acids, which can have a solid nonprotein structure. "Solid" refers to a type of binding, which is comparable to the characteristic protein type of peptide binding.

The protein content of milk is influenced significantly by the feeding and varies between 3.0 and 3.6%. For cheese making this has a special significance, as the yield (see 7.3.12) in cheese making is controlled by the protein content.

The protein content of the milk is not uniform, but consists of two fractions, i.e., the casein and the whey proteins (serum proteins). These fractions can be further split into components and are different in chemical composition. Milk proteins with specific characteristics are shown in Table 2./4.

Milk proteins not only are important for the manufacture of traditional dairy products but also have a multitude of functional characteristics and high nutritional values, e.g., casein is the major component of cheese and contributes its typical consistency to acidified products. Individual specific protein fractions such as caseinate, whey protein concentrates or coprecipitates have wide significance in the spectrum of foods such as in infant formula and even some pharmaceutical products.

Casein, which is 80% of the milk protein, is arranged in milk in precisely formed micelle (clusters of individual molecules, which are kept together by lateral forces). Apart from the casein, micelles contain a fairly high percentage of colloidal calcium phosphate. Within the range of normal technical processing conditions, they are stable when it comes to thermal and mechanical processing. The casein micelle is sensitive to changes in charge. When milk turns sour, a structural change can be observed at pH <5.0, a gel is formed (see also 7.3.4), and minimal stability is reached at the isoelectric point.

- The isoelectric point (IP) for casein is at 4.6–4.7 (the IP for skimmed milk is 4.65, corresponding to an SH value of 33-35).

Table 2./4 Specific characteristics of milk proteins

Protein fraction	Percentage point [%]	Isoelectric point [pH]	Molecular weight [Dalton]
Casein	79	4.6	$2-18 \times 10^8$
α -Casein ¹	45-55	5.1	22500
κ -Casein	8-15	4.1-4.5	19000
β -Casein	23-35	5.3	24000
γ -Casein	3-7	5.8-6.4	$11-20 \times 10^3$
Whey proteins			
β -Lactoglobulin	7-12	5.2	18300
Serum albumin	0.7-1.3	4.8	69000
α -Lactalbumin	2-5	5.1	14000
Immunoglobulin	1.9-3.3	4.6-6.0	$15-100 \times 10^4$
Protease peptone	2-6	3.7	$4-40 \times 10^3$

¹ The index S means the sensibility of this fraction vis-a-vis Ca^{2+}

Although, as can be seen from Table 2./4, the isoelectric point of the casein components is in the pH range 4.1-4.6, they show such a strong bonding that casein is always precipitated in its entirety. Further, casein is unstable when exposed to enzymes (proteinases, phosphatases and glucosidases), and a gel can also be formed (cheese manufacture). Whey proteins are the protein fraction of cow's milk which remains in solution after an isoelectric or enzymatic precipitation (in the whey during cheese manufacturing). In their negatively charged state, they show a spherically closed spatial structure (very close to perfect spheres or ellipsoid-type peptide chains). Further, they are relatively stable in an enzymatic environment. At temperatures $> 70^\circ\text{C}$ denaturation begins; i.e., the structure-stabilizing forces cannot cope with the thermal stress and a structural change takes place. There is a simultaneous loss of solubility and a change of functional characteristics. During heat denaturation the whey proteins enter partially into complex bonding with the κ -casein.

The whey proteins are groups of compounds, called albumin (β -lactoglobulin, α -lactalbumin, serum albumin) and globulin (immunoglobulin). In dairy technology, the thermodenaturation of whey proteins plays a role, as it is linked with desirable and undesirable modifications:

- a) A firmer gel structure in acidified products, especially in yogurt
- b) An improved water retention capability
- c) A reduced whey excretion with acidified gels
- d) Yield increase in fresh cheese products
- e) Cooked taste
- f) Soiling of surfaces in heat exchangers
- g) Reduced lab precipitation of milk
- h) Change of functional properties in milk powders (see 9.5.2.1)

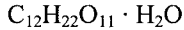
Nutritionally the whey proteins are very high in quality, as they have a biological value of 124. In comparison, casein has 73 and milk has 88.

- The biological value indicates, how many grams of body protein of an adult person can be replaced by 100 g of food protein. As a reference the biological value of whole egg protein is 100.

During cheese manufacture, the whey proteins go into the whey; processes for a whey utilization where the protein can be recovered completely have gained significant interest (see Section 10.2). Apart from the casein, albumin and globulin, milk contains traces of proteoses and peptones and whey contains enzymatically produced glycomacropeptides.

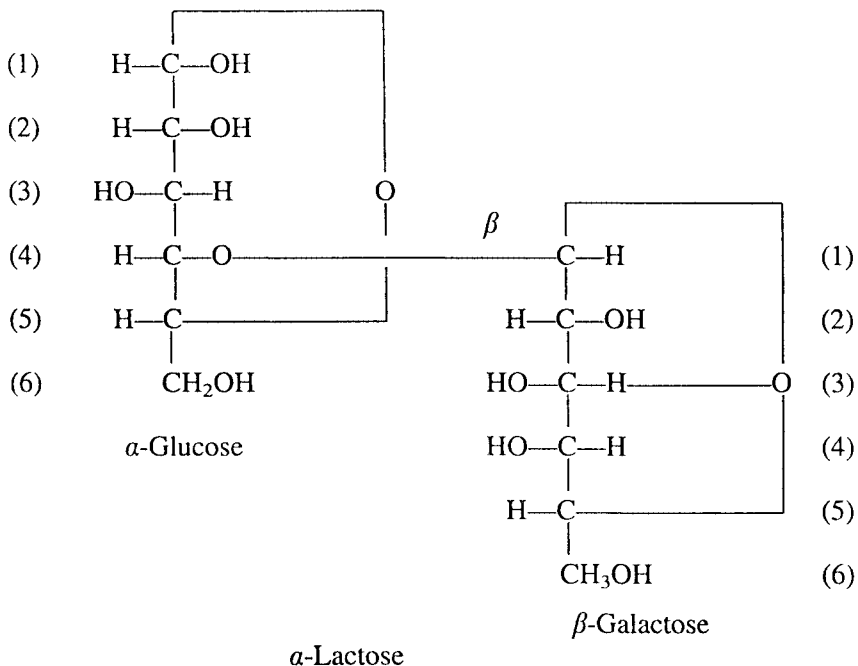
2.3.1.4. Milk sugar (lactose)

Lactose is the characteristic carbohydrate of milk, is a disaccharide with the formula



The chemical reaction of sugar shows, that it does not exist in the form of a chain but has a ring structure. With glucose and galactose, the ring forms from the C1 atom to the C5 atom via an oxygen bridge. Bonding takes place between the C4 atom of glucose and the C1 atom of galactose. The position of the OH group on the C1 atom is labeled in function of direction (α -position for the right direction and β -position for the left direction).

Lactose exists in α and β forms, and in an aqueous solution both forms are in equilibrium. On heating to 93.5 °C, the equilibrium is disturbed, and the α -lactose is crystallizing in the form α -lactose monohydrate. This crystallized product is the commercial lactose (see 10.2.3.2). It consists of the two monosaccharides glucose and galactose.



Compared to other disaccharides, lactose has very low sweetening power, about 30% that of sucrose, and the solubility is also lower.

Lactose has technological importance during all acidification processes involving milk (acidified products, cream ripening), in which it serves as the substrate for the lactobacillus bacteria, as well as during its direct manufacture. In addition, lactose can participate in reactions during technological process, leading to the formation of lactulose and in Maillard reactions.

Lactulose is a disaccharide, consisting of galactose and fructose, which is formed in small quantities by isomerization of lactose during the heat treatment of milk. Toxicologically it is safe, and it is supposed to contribute to the “nutritionally advantageous” bifidus flora in the intestines. Since lactulose formation depends on the intensity of the thermal treatment, it can be used as a distinctive characteristic for the heat treatment of milk (sterile milk, UHT milk).

The Maillard reaction is a reaction of sugar with amino acids under heat. In milk, the major reactive compounds are the free amino acid lysine and lactose. In milk products with a high thermal load, the Maillard reaction can lead to browning as well as changes in taste and smell.

2.3.1.5. Milk salts

Salts, existing as compounds of acidic anions and metallic cations or other cations, dissociate in an aqueous solution into their ions.

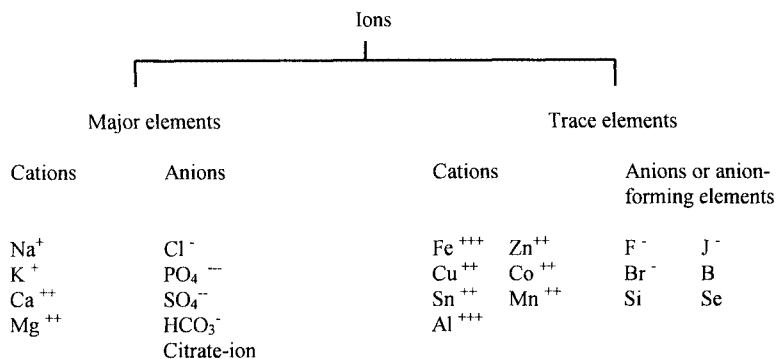
- Ions are singly or multiply positively or negatively charged atoms, groups of atoms or molecules that form during the dissociation of a substance in water.

In the broadest sense, milk salts contain all those milk substances which exist as ions or can be ionized, except hydrogen and hydroxyl ions. More specifically—apart from the ions of inorganic and organic salts—proteins can be included, as their ionizable groups can form salt-like compounds with cations. However, we include only the metallic cations as salts as well as the inorganic and organic anions. If ions exist in a very high concentration, then we talk of major elements; if they exist in lower concentrations, then we talk of trace elements.

- The exact salt content of milk can be indicated by the ion concentration.

Previously, the determination of the ion concentration was very difficult and laborious; total levels were usually calculated via the nondissociated compounds, e.g., the mineral content. In this context, the ash content of milk is indicated as 0.7–0.8%, which can be determined very easily by ashing the milk. However, the ion concentration (or salt content) is not identical to the ash content, as milk does not contain ash, and also during the ashing of milk organic acids are destroyed and other ash residues cannot be termed as salts. Overview 2./2 shows the major ions and Table 2./5 shows the major elements.

Overview 2./2 Ions in milk (selection) ¹



¹See Töpel, A.: Chemie und Physik der Milch, 2nd edition, Leipzig, VEB Fachbuchverlag, 1981.

In addition, in milk there is a salt equilibrium; i.e. the individual salt ions are in an equilibrium with the nondissociated molecules. From the observation of these systems in equilibrium we can deduce the state of dissociation and solution (see Table 2./7). Salts exist in a true solution, in colloidal solution or bound to proteins. In milk, 33% of calcium is solubilized, 45% is bound in colloidal form milk at 45%, and the balance is bound to casein. However, the analogous distribution of phosphates is at levels of 33, 38 and 20% with 1% bound to lipids (in the fat globule membrane). The colloidal solution of the compound is based on the fact that due to their charge they are surrounded with a hydrogen sphere and are kept in solution.

Major and trace elements have a great importance for the human and animal organism, especially for the growing individual. They are part of the enzyme system, the basis for controlling process in the body, as in the nervous system, energy transfer, growth of bones, blood coagulation and coping with stress.

Special technological significance is conferred upon calcium, as it must be present in sufficient quantities for protein coagulation to occur (see 7.3.4). The citrates play a special role during butter flavor development.

The salt content depends upon factors such as stock, stage of lactation, health (e.g., disorders in secretion can change the salt content significantly) and above all the mineral supply by the feed. Highly visible changes of the salt content are evident during infections of the udder.

Table 2./5 Levels of major elements in decreamed milk¹

Element	Average levels	
	in %	in mg / 100 cc
Sodium	0.05	50
Potassium	0.15	145
Calcium	0.12	120
Magnesium	0.01	13
Phosphorus (total)		95
Phosphorus (organic as PO ₄)	0.21	75
Chloride	0.10	100
Sulfate	0.01	10
Carbonate (as HCO ₃)	0.02	20
Citrate (as citric acid residue)	0.20	175

¹ See footnote to Overview 2./2.

2.3.1.6. Enzymes

Enzymes (formerly called ferments) are molecular compounds with complicated structures, consisting of a protein (the so-called apoenzyme) and a functional group (prosthetic group or coenzyme). Enzymes are the biocatalysts of living cells, which permit total metabolism by reducing the activation energy and increasing the reaction velocity. If the enzymes remain in the cells, react there and are transferred only after the dissolution of the cell into a substrate, then we define them as endoenzymes. Ectoenzymes are those enzymes which are constantly transferred into the substrate and accelerate chemical reactions.

The milk enzymes originate partially in the blood and are transferred via the milk formation cells in form of natural enzymes and partially as metabolic products of microorganisms which have found their way into the milk in form of bacterial enzymes. The origin of milk enzymes cannot always be clearly demarcated. Some of the proteases, lipa-

ses, phosphatases or catalases can have a natural as well as a bacterial origin.

The reaction of the enzymes is very specific and depends above all on the temperature and pH value. At low temperatures their reaction is delayed, but they are still active. At temperatures $>70^{\circ}\text{C}$ the deactivation of the enzymes begins (see Figure 2./4). The optimum temperature range is $30\text{--}40^{\circ}\text{C}$. Some of the reactions are:

- Glycolysis → Carbohydrate degradation (lactose)
- Lipolysis → Fat degradation
- Proteolysis → Protein degradation

The most important milk enzymes, their reaction and significance are found in Overview 2./3.

Today, industrially manufactured enzymes are used in the manufacture of dairy products, such as lab(or rennet) or microbial precipitation enzymes used in cheese manufacture, lactase for the hydrolytic splitting of lactose into glucose and galactose, microbial proteinase for the modification of functional properties of milk and dairy products and lipase for the flavor enhancement by fat degradation.

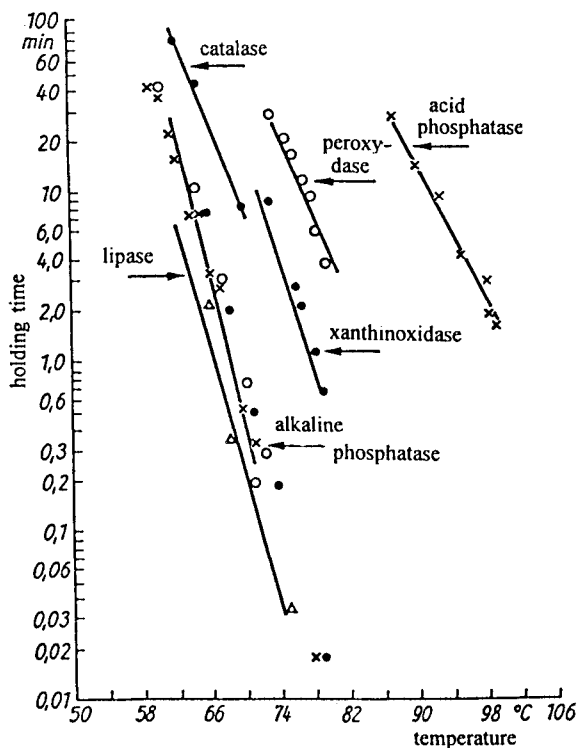


Figure 2./4
Time/temperature relationships for the inactivation of milk enzymes

2.3.1.7. Vitamins

Vitamins are formed in plants through the influence of sunlight. They are essential reagents for men and animals for maintaining and growth of cell substance, as well as to guarantee the normal functioning of the organs. They function with the minutest amounts and do not provide energy.

Vitamins are transferred into the body via food or are made out of provitamins. If the level of vitamins contained in food is too low, then deficiencies (hypo- and avitaminosis)

can occur, which may result in death. In a few cases, the intake of too high levels of vitamins, e.g., through supplements can lead to disturbances (e.g., hypervitaminosis).

Overview 2./3 The most important enzymes in milk

Enzyme	Origin and function	Significance
Peroxidase	Splitting of atomic oxygen from peroxides; transfers easily to other compounds $2\text{H}_2\text{O} \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ at $T \geq 85^\circ\text{C}$ $t \geq 10$ s inactivation	Proof of sufficient heat treatment of milk based on UHT process (see 4.2.7.2)
Catalase	Splitting of oxygen in molecular form from hydrogen peroxide $2\text{H}_2\text{O} \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ The level is high in colostrum milk, milk from old cows or cows with mastitis. Inactivation during pasteurization	Natural levels in milk are absent to low; they indicate the hygienic status of the abnormality of milk (catalase reaction)
Phosphatase	Important enzyme group of the hydrolases. Catalyzing the hydrolysis from phosphoric acid esters.	
Alkaline phosphatase	The optimum reaction is found at pH 9.0–9.5 and 37°C ; inactivation at $70\text{--}75^\circ\text{C}$	Proof of sufficient heat treatment for milk in short-time heat-treatment processes
Acidic phosphatase	The optimum is at pH 4.0–4.5, inactivation at 100°C	Survives the pasteurization process, is one of the heat-stable enzymes.
Xanthinoxidase	Adsorbed into the fat globule membranes, also called Schardinger enzyme	Oxidizes xanthine with methylene blue and water into uric acid.
Lipase	Is an esterase which hydrolyzes the ester bonds of fats. Found at low levels in milk as a natural enzyme. Bacterial lipases indicate a strong contamination or recontamination with microorganisms. Optimum is pH 8.5 to 9.1 and $38\text{--}40^\circ\text{C}$; inactivation during high temperature treatment at $T \geq 85^\circ\text{C}$	Splits milk fat from defective fat globule membranes, develops noticeable taste and flavor modifications in milk and dairy products (rancidity). Bacterial lipase in cream and butter indicates recontamination.
Protease Proteinase	Denatures proteins and their subgroups while cutting the peptide bonds. Milk contains low levels of natural protease, bound to casein. They survive the pasteurization. Bacterial protease are formed in large quantities from desirable and undesirable microorganisms.	Bacterial protease split proteins into products of desirable quality, e.g., during cheese ripening, but can cause spoilage and taste defects. Releases important amino acids, which are necessary for the growth of microorganisms.
Carbohydrase Amylase Diastase	Splits the glycoside bond in carbohydrates. Natural carbohydrate in milk, low levels, modifies starch into maltose. Optimum condition at pH 7.4 and 44°C . Inactivation during pasteurization.	
Lactase	Bacterial carbohydrate, formation from the metabolism of lactobacillus and yeast. Splits lactose into glucose and galactose.	Base for lactic fermentation and alcoholic fermentation in acidified dairy products.

Milk contains all the essential vitamins, but in varying and sometimes insufficient amounts. The vitamin content of raw milk is influenced mainly by the feeding and health of the animal. The vitamin content can be reduced further by treatment. Apart from the vitamins shown in Overview 2./4, milk contains the fat-soluble vitamins E (tocopherol), F and K as well as the water-soluble vitamins B1 (thiamin), B12, vitamin H, pantothenic acid, folic acid and nicotinic acid amide.

Overview 2./4 Important vitamins in milk

Type	Available in	Level [mg/l or mg/kg]	Significance	Sensitivity	Daily Requirement For humans [mg]
Fat soluble					
Vitamin A Retinol Provitamin Carotene	Cow's milk Summer butter Winter butter Cheese	0.02–0.2 1–20 0.2–5	Results in yellow color of butter; if deficient causes skin and eye damage (night blind- ness)	To UV rays and oxygen; sur- vives braising	1–2
Vitamin D Cholecalciferol Provitamin Ergosterol	Cow's milk Butter	0.0002– 0.0004 0.0004– 0.002	Promotes tooth growth and bone reconstitution when deficient; causes rachitis and infections	Not sensitive to oxygen and heat	0.01
Water soluble					
Vitamin B2 Lactoflavin Riboflavin	Cow's milk Whey Milk powder Whey powder Kefir powder	0.2 0.1–0.27 1–3 2–6	Discoloration of whey (green-yellowish), im- portant for growth, esp. for lactobacilli. When deficient, intesti- nal illness.	Not sensitive to oxygen and heat	2–4
Vitamin B6 Adermin	Cow's milk Whey	0.01–0.15 0.1	When deficient, nervos- ness and insomnia	Not sensitive to heat and acid, light sensitive	2–4
Vitamin C Ascorbic acid	Cow's milk Whey	0.5–2.8 1.0	When deficient, apathy during spring, infection sensitive, tooth decay	Sensitive to heat and light	30–100

2.3.1.8. Gases and organic acids

Gases. Shortly after milking, milk contains about 5–10 vol.% carbon dioxide, 2–3 vol.% nitrogen and 0.5–1.0 vol.% oxygen. The foaming during hand milking results in a loss of 50% of the gases. During storage, the gas content in milk is further reduced.

Organic acids. Milk contains naturally occurring citric acid (about 2.45 g/kg milk). Lactic acid, butyric acid as well as all the other acids in milk are metabolic products of fermentation processes by microorganisms.

Lactic acid, which is produced during the fermentation of lactose, has special importance, because the pH can be reduced in a controlled manner (due to its production and dissociation), e.g., during the production of acidified products.

During the lactic acid fermentation, two acid configurations are developing, e.g., L(+) lactic acid and D(–) lactic acid. D and L are named for the spatial position of the OH group of the C2 atom (L = left position, D = right position); the polarization of the light is characterized by (+) and (–). An L(+)lactic acid turns right, a D(–) lactic acid turns left. In addition, there is an insignificant amount of the optically inactive raceme DL-lactic acid.

The percentages of L(+) and D(–) lactic acid manufactured during the fermentation of lactic acid determine the type of lactic acid bacteria. For example, *Lactococcus lactis* or *Streptococcus salivarius* subsp. *thermophilus* (see 2.4.3) produce mainly L(+) lactic acid, *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Lactobacillus delbrueckii* subsp. *lactis* are forming mainly D(–) lactic acid. L(+) lactic acid is also formed in the human body and has important metabolic functions. D(–) lactic acid is not formed. Therefore, mostly those combinations of microorganisms are used during the manufacture of acidified products, which form more than 50% of L(+) lactic acid.

2.3.1.9. Foreign material

The utilization of chemicals in agriculture in the form of insecticides and pesticides as well as chemotherapeutics (to fight against animal diseases) results in residues of these compounds in milk. In addition, environmental contamination by the industry and other factors of civilization contributes to the occurrence of foreign material in milk. Foreign material in foods can be defined as follows:

- Foreign materials are naturally not present in food nor introduced by normal physical treatment.

The possible sources of contamination are shown in Overview 2./5. In order to exclude injury to humans as much as is possible due to consumption of dairy products and other foods, tolerances have been set through laws and regulations and have to be respected. They are shown in Table 2./6.

Apart from possible injury to humans or animals due to contamination with foreign material, defects in the technological process have to be expected. The activity of butter or cheese cultures and yogurt manufacture can be reduced significantly by residues of pesticides, herbicides, insecticides and antibiotics (used to prevent animal diseases). All other materials which reduce or inhibit the growth of microorganisms are grouped together under the term inhibitors.

Table 2./6 Proposed tolerance values for milk and dairy products in mg/kg for selected foreign materials

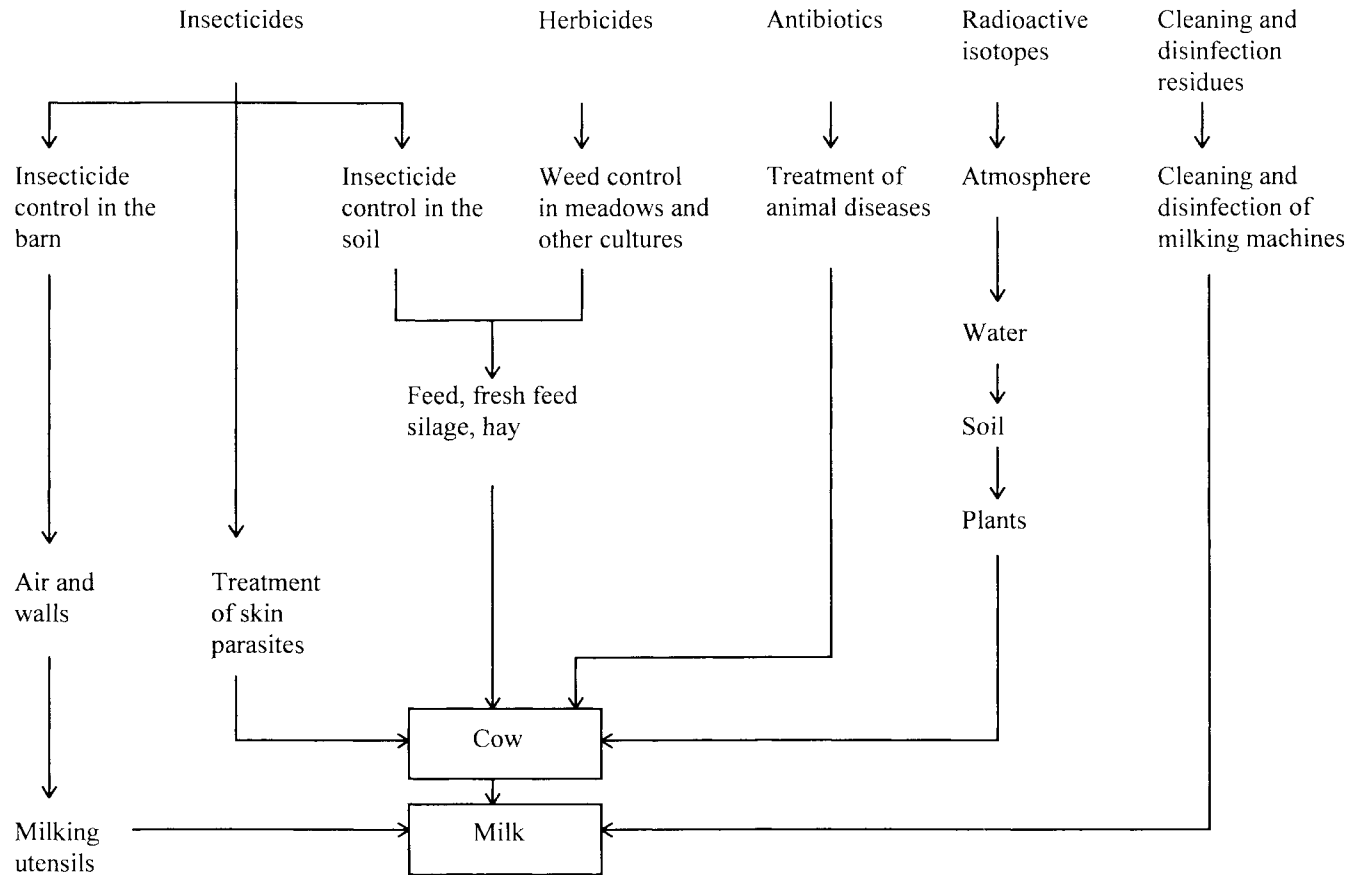
Foreign material	Tolerance values for		
	Animal fats	Dairy	Food and baby food
DDT	1.0 ¹	1.0 ¹	0.02
Lindane	0.5	0.02	0.02
Trichlorphon	0.02	0.02	0.02
Dichlorphos	0.02	0.02	0.02
Butonat	0.5	0.02	0.02
Dimethoat	0.004	0.004	0.004
Carbaryl	0.02	0.02	0.02
Hexachlorbenzen	0.5 ¹	0.5 ¹	0.02
Lead		0.1	
Zinc		5.0	
Copper		0.5	
Tin		250	
Mercury		0.02	
Nitrate		10	

¹ On fat basis.

The qualitative and quantitative proof of these antibiotics is often very difficult and requires considerable analytical facilities and considerable efforts. However, detection is very important, as a milk containing inhibitors can be used for processing only in certain cases. The IDF has recommended the following analytical methods for inhibitors :

- Inhibitor test with *Bacillus stearothermophilus*
Plate test (IDF standard 57:170, plate test with indicator

Overview 2./5 Contamination sources for foreign objects



- tube or microtiter test (brilliant black reduction test, tube diffusion test)
- b) Inhibitor test with *Streptococcus salivarius* subsp. *thermophilus*
Accusphere test
Acidification test
bioluminescence (ATP) test
 - c) Inhibitor test with *Bacillus subtilis*
Arla microtest
Bacillus subtilis test (AOAC method)
 - d) Inhibitor test with *Sarcina lutea*
 - e) Yogurt inhibitor test

These tests, which are oriented toward growth and metabolism inhibiting microorganisms, can also be used as identification and confirmation tests, determining a certain group or a multitude of antibiotics, such as:

- a) Enzyme test (Penzym process)
- b) Latex agglutination test (spot test)
- c) 3-plate test
- d) 6-plate test
- e) Microbiological receptor test (charm test II)
- f) High voltage electrophoresis

2.3.2. Physical-chemical characteristics

2.3.2.1. Terms

The physical-chemical characteristics of milk are a result of the characteristics of its individual components and their interactions with each other. The stability of a system—and its structure above all—depends on the interaction of the phases and the compounds.

- Structure is a level of order of atoms, ions and electrons determined by the interactions of dispersed particles and is characterized by the texture of a material, i.e. such as solid, semisolid, gel or liquid.

Structure consists of the macrostructure (visible to the eye), the microstructure (visible with a light microscope), and the ultrastructure (visible with an electron microscope). The structural characteristics are shown by the texture.

- Texture represents the structural characteristics of food, determined mainly by organoleptic, rheological and optical methods.

Sensorial methods (i.e., noticeable with our sensorial organs) are described extensively in Section 2.6. In optical methods, the microscope is widely used. In order to describe the structural characteristics with reproducible parameters, rheological methods are used.

- Rheology is the science of deformations, including the flow of fluid and solid bodies while subjected to mechanical forces. Rheological dimensions are viscosity, shear, resistance, pressure, flow, deformation.

Rheological and colloquially termed characteristics like hardness, viscosity, plasticity, elasticity, deformation, adhesion are often grouped under the term consistency.

- Consistency is the characteristic of a body which offers resistance to deformation.

The determination of consistency is done by organoleptic and rheological (i.e., physical) methods, of which the most important ones are shown in Figure 2./5. Only three basic physical parameters are determined

- a) Force in N
- b) Length in m
- c) Time in s

These data result then in the following characteristics, which are necessary to evaluate consistency or texture

- a) Determination of the force for a predefined deformation
- b) Determination of the deformation by a predefined force
- c) Determination of the time to achieve a predefined deformation with a predefined force

The physical-chemical characteristics are influenced to a great extent by the concentration and the level of distribution of the ingredients.

2.3.2.2. Distribution levels and forms of solutions

If one or several compounds are distributed in another mixture, a so-called disperse or dispersed system is created. Milk is such a system; it is a polydisperse system, because the individual ingredients—present in different particle sizes (Figure 2./6) and different levels of dispersion—exist in water.

In a disperse system we distinguish between the dispersed ingredients or phase (e.g., milk ingredients) and the dispersion medium as a continuous liquid phase. As a function of the aggregate state of the dispersed components we can show the systems as follows (see Overview 2./6). Looking at the particle size of the dispersed system, we observe some significant variations in different characteristics. The classification resulting from this is shown in Overview 2./7.

In coarsely dispersed systems, particles can be seen with the naked eye (coagulated protein), having a particle size of > 0.1 mm. In finely dispersed systems the particles can be seen with simple optical means, as the particle size is $0.5\text{--}100\ \mu\text{m}$ ($1\ \mu\text{m} = 1\ \text{micrometer} = 10^{-3}\ \text{mm} = 10^3\ \text{nm} = 10^3\ \text{nanometer}$). Most important in this range are the fat globules of milk with an average size of $4\ \mu\text{m}$. Normally, we find fat in the fat globules in liquid form and describe it as an emulsion.

- Emulsions are dispersed dual phase systems, i.e. a complete blend of two liquids which are not blendable under normal conditions. One liquid is dispersed in form of small droplets in another liquid.

Colloid disperse systems or colloidal solutions have a particle size of $1\text{--}500\ \text{nm}$. Their differentiation from molecular disperse systems is very difficult, since their particle size is $< 1\ \text{nm}$. These solutions are real solutions, where the soluble compounds exist in the form of ions as well as individual molecules. Casein is dissolved in colloidal disperse systems.

Serum proteins exist partially as colloidal disperse systems but mainly as a molecular dispersed systems. Lactose and milk salts exist in real solutions.

Of special interest are the protein dispersions and their flow characteristics, as they are submitted to significant modifications during the treatment of milk e.g., in cheese manufacture, acidified products, concentration, drying and others.

Overview 2./6 Forms of dispersions (disperoids)

Dispersed compound	Dispersion medium	System name	Examples from the dairy sector
solid	liquid	suspension	coagulated casein in whey
solid	gaseous	aerosol	dust in air during milk drying
liquid	liquid	emulsion	raw milk, raw cream
gaseous	liquid	foam	whipped cream
liquid	gaseous	fog	sprayed milk in a tower

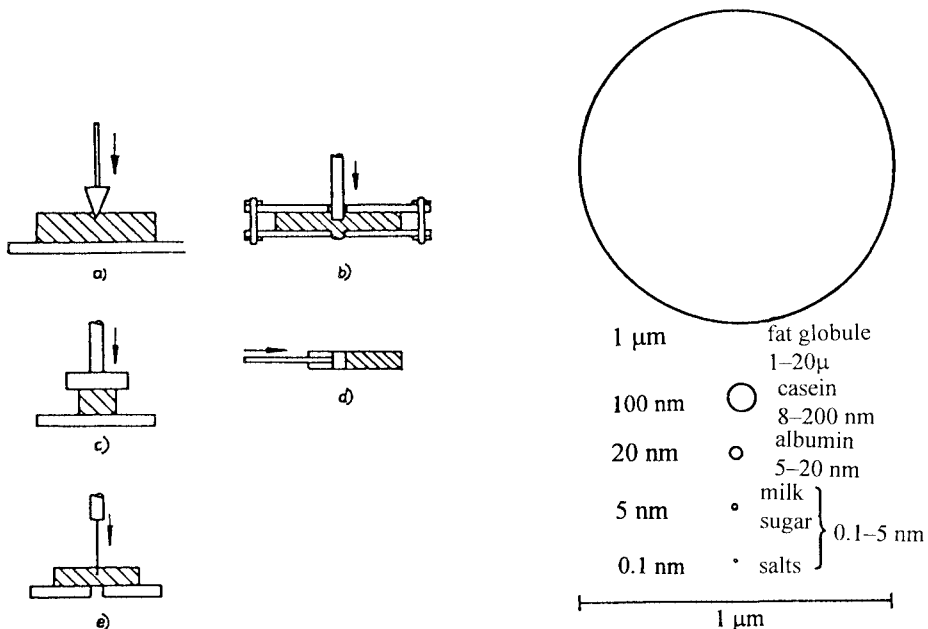


Figure 2./5 Physical principles for the determination of consistency and texture evaluation of foods

(a) Penetration (b) Shear (c) Compression
(d) Extrusion (e) Cutting wire

Figure 2./6 Comparative sizes of milk components

2.3.2.3. Density

Density is the relationship of the mass of a body to its volume

$$\rho = \frac{m}{V}$$

ρ density in g/cm^3 or g/ml or kg/dm^3 or kg/l or kg/m^3

m mass in g or kg

V volume in $\text{cm}^3 = \text{ml}$, $\text{dm}^3 = \text{l}$ or m^3

Overview 2./7 Classification of disperse systems as a function of particle size and characteristics

	molecular disperse systems (real solution)	colloid disperse system (colloidal solution)	finely dispersed system
particle size	1 nm	1–500 nm	500–1000 nm
filtration	passes all filters	passes simple filter but not ultrafiltration	passes simple filter but not ultrafiltration
distribution in solvent	homogeneous	homogeneous	settling
observation of individual particles	individual particles not visible "clear"	individual particles not visible "clear"	individual particles visible with magnifying glass or microscope "cloudy"

The density of milk varies between 1.027 and 1.035 g/cm^3 as a function of the type and quantity of the dispersed particles (emulsified, colloidal or soluble). With increasing fat content, the density decreases; density increases with an increasing protein, lactose and mineral content. Density is influenced by temperature (see Figure 2./7), average values for densities at 20 °C and 1.013 bar (standard atmospheric pressure) in g/cm^3 are:

Whole milk	1.027–1.032	Skimmed milk	1.033–1.036
Cream	1.0035–1	Buttermilk (heat serum)	1.0214
Whey	1.025–1.027		

Density is technologically important when calculating the raw milk quantity, when determining adulterations, for automatic fat standardization, for the determination of water in buttermilk and when manufacturing concentrates for longlife products. Further the fat-free dry matter TS_{FF} (and from that the dry matter content TS) can be calculated.

$$TS_{FF} = \frac{ld_{20}}{4} + \frac{f}{4} + 0.55\%$$

$$TS = TS_{FF} + f$$

$$TS = \frac{ld_{20}}{4} + 1.2 \cdot f + 0.55\%$$

A rapid method for the determination of density in milk uses the lactodensitometer. The term ld_{20} is the lactodensitometer reading at 20 °C, used for the determination of the dry matter content.

$$\rho = \frac{1d20 + 1000}{1000}$$

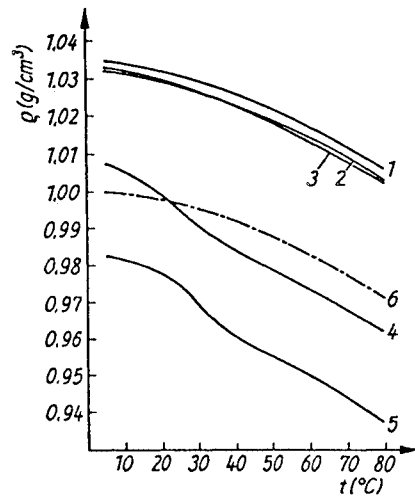


Figure 2./7
Density of milk and cream as a function of their temperature
 (1) Skim milk (2) Fresh milk 3.5% fat (3) Raw milk 4.5% fat (4) Cream 30% fat (5) Cream 48% fat (6) Distilled water

2.3.2.4. Boiling and freezing point

The boiling point for milk is 100.2 °C, slightly higher than for pure water, as lactose and salts (properly dissolved compounds) reduce the steam pressure of the liquid. Steam pressure that is identical to atmospheric pressure is obtained only at higher temperatures.

The average freezing point of raw milk is at -0.526 °C; of pasteurized milk in the range -0.517 to -0.521 °C. This is influenced (see also the boiling point) by the dissolved lactose and the similarly dissolved ions of the milk salt and a few other compounds with a relatively low molecular mass.

This relationship permits to detect adulteration with water or with additives e.g. salts, disinfectants or neutralizing agents.

The freezing point of raw milk has a lower value of -0.515 °C. Values of < -0.500 °C indicate adulteration with water. Values of > -0.62 °C indicate adulteration with salts. The freezing point can be modified by gassing/degassing of milk, lactose splitting or pH modification.

During freezing of milk, demixing can occur. First water is frozen, resulting in enrichment of certain ingredients in the nonfrozen part. In a completely frozen milk, we find protein, lactose and minerals in the bottom part of the ice and fat in the upper part. After thawing, the original distribution cannot be achieved again, especially the fat distribution.

- Sampling of frozen raw milk for quality control purposes of the raw milk results in incorrect analytical results.

The chemical reactions of milk have extraordinary importance in dairy technology. All microbiological processes, the process of butter manufacture, protein precipitation as well as pasteurization results, depend on the type and extent of chemical reactions. Results are either neutral, acidic or basic.

2.3.2.5. Chemical reactions—pH value

Soxhlet-Henkel value (potential acidity or titrable acidity). The acid reaction as it occurs in milk and dairy products is often expressed in terms of the Soxhlet-Henkel value (SH, SHV).

- The SH value indicates how many cm³ of a caustic solution with a concentration c (NaOH) of 25 mol per cm³ (N/4) are required to neutralize 100 cm³. As an indicator, about 1 cm³ of a 2% alcoholic phenolphthalein solution is added.

Absolutely fresh milk from healthy cows has an SH value of 6.4–7.0. Part of this is due to acidic salts, e.g., NaHCO₃, and the free organic acids (mainly citric acid); the balance is due to casein, which reacts to NaOH like an acid. The increase of the SH value after milk coagulation is due to the formation of lactic acid by the corresponding bacteria, especially lactic acid bacteria.

SH values in raw milk < 5.0 indicate mastitis, defects in feeding or negative microbial influences, resulting in reduced lab coagulation or taste defects in milk. SH values of 8.0–9.0 result in a noticeable sour taste, at SH values > 10 protein coagulation during heating of the milk occurs.

SH values of 10–12 will not necessarily lead to heat precipitation, because due to breeding activities a higher value can be obtained. Then the acidity has to be determined by the pH value, as the SH analysis cannot determine the dissociated part of the acid precisely.

As the dissociated part of the acid cannot be determined precisely by SH analysis (and nondissociated acidic parts can also be neutralized too), we call this the probable potential acidity. This determination becomes more imprecise the lower the percentage of titrable serum becomes (e.g., cream with a high fat content).

Other acidity determinations by titration result in Thörner degrees and the Dornic grade. Sometimes acidity is given as g lactic acid per 100 cm³ milk or % lactic acid. The relationship between the different values for the potential acidity is given in Table 2./7.

pH value (actual acidity). Of special interest during microbial and other processes is the mass of the dissociated part of the acid, expressed as the pH value. This means the determination of the mass and activity of the dissolved H₃O⁺ ions. As this method is more precise and realistic, this titered acidity is termed the actual acidity.

The pH value is derived from the ion product of water. Purest, multiply distilled water still shows a minimal conductivity. It is based on the dissociation of water into hydrogen ions (H⁺), which are hydrated to hydronium ions (H₃O⁺), and hydroxide (OH⁻) ions.



The balance of this reaction is more toward the left side. The ion product $c(\text{H}_3\text{O}^+) \times c(\text{OH}^-)$ at 22 °C is only 10⁻¹⁴ mol/l and is strongly influenced by temperature. At a constant temperature the ion product remains constant for all aqueous solutions. One liter of chemically pure water and one liter of all neutral aqueous solutions contain (at 22 °C)

$$\begin{aligned} 10^{-7} & \text{ g H}_3\text{O}^+ \text{ ions} \\ 10^{-7} & \text{ g OH}^- \text{ ions} \end{aligned}$$

Water is therefore a very weak acid, but also a very weak base.

Table 2./7 Comparison of titration acidity ¹

Soxhlet-Henkel Value	Thoemer degrees	Domic grade	lactic acid calculated
1	2.5	2.25	0.0225
2	5.0	4.50	0.0450
3	7.5	6.75	0.0675
4	10.0	9.00	0.0900
5	12.5	11.25	0.1125
6	15.0	13.50	0.1350
7	17.5	15.75	0.1575
8	20.0	18.00	0.1800
9	22.5	20.25	0.2005
10	25.0	22.50	0.2250
20	50.0	45.00	0.4500
30	75.0	67.50	0.6750

¹ See Töpel, A.: Chemie und Physik der Milch, 2nd edition, Leipzig, VEB Fachbuchverlag, 1980

When the following condition exists:

$$c(\text{H}_3\text{O}^+) = c(\text{OH}^-) = 10^{-7} \text{ mol/l or} \\ -\log c(\text{H}_3\text{O}^+) = \text{pH} = \log c(\text{OH}^-) = \text{pOH} = 7$$

we have a neutral solution. With an excess of H_3O^+ the pH value diminishes and the solution reacts in an acidic way. With an excess of OH^- the pH becomes > 7 and the solution reacts alkaline (basic). We have

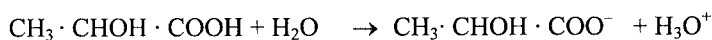
$$\text{pH} + \text{pOH} = 14$$

- The pH value of a solution is the negative decadic logarithm of the hydronium activity (colloquially called hydrogen activity).

The pH value of water or an aqueous solution changes with the addition of ingredients which can react as an acid (H^+ donor) or base (H^+ acceptor). The solution then reacts as either an acid or base. (Figure 2./8).

- In aqueous solutions the pH value serves to determine the acidity or alkalinity, caused by the hydronium ions.

Lactic acid fermentation \rightarrow lactate ions + hydronium ions



In Table 2./8 the acid values for milk and the pH values are compared. The pH of fresh milk from healthy cows is at 6.4–6.7. It remains nearly constant with a minor increase in the hydronium activity. This increase is due to the buffering capacity of the buffers present in milk.

- Buffers are compounds which resist a pH change. Buffering solutions (buffering systems) consist of a weak acid and their alkaline salt or of a weak base and their salt.

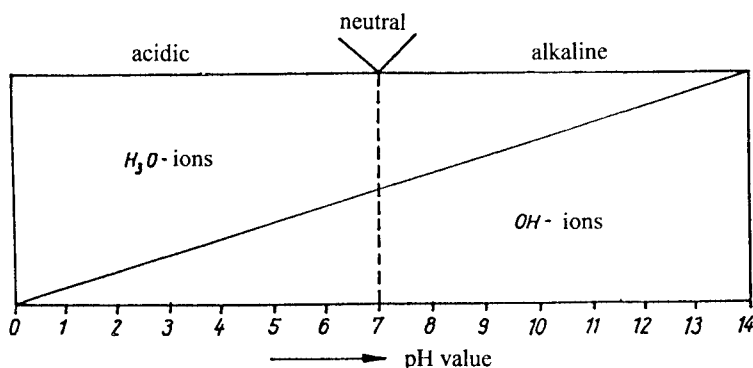


Figure 2./8 Concentration of H_3O^+ and OH^- ions

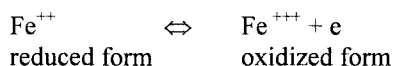
Table 2./8 pH value compared to SH number

SH number	6.5	7	8	9	22	25–30
pH value	6.5	6.45	6.15	6.1	5.85	5.0–4.6

In milk, the lactate ions (formed by lactic acid fermentation) form a buffering system with the non-dissociated lactic acid.

2.3.2.6. Redox potential

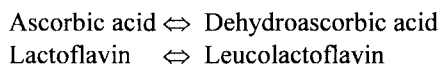
Reduction and oxidation processes involve changes in charge due to transitions of electrons e in compounds which participate in reactions. These processes can be shown as reaction equations, e.g.,



and the currents thus created can be determined with voltmeters. Other methods include redox indicators, which show the potential by changing color. For example, the indirect bacterial count can be determined by way of a reduction sample with resazurin or methylene blue as an indicators. The result of the current determination is expressed as redox potential.

- The redox potential is a measure of the amount of energy which is liberated during acceptance or donation of electrons.

Participating in the redox potential of milk are the redox systems



as well as dissolved oxygen and sulfhydryl groups of the whey proteins. The strongest influence on the redox potential is exerted by the active metabolism of microorganisms; therefore the redox determination indicates the level of the microbial load (reduction sample).

Control of the redox potential is very important for the storage of milk products in order to recognize oxidation processes and therefore prevent quality deterioration. During the heating of milk, the redox potential is decreased due to oxygen elimination and the cracking of sulfhydryl groups. Redox potential of milk and dairy products are (data in mV):

Raw milk	+250 to +300	Pasteurized milk	+100
Melted cheese	+50	Yogurt	-150
Emmenthal cheese	-300		

2.3.2.7. Viscosity

The dynamic viscosity η is a parameter related to the inner friction of a liquid or fluid. It is reduced when temperature is increased. Due to the friction of the fat (emulsified in milk) and the dispersed protein, the viscosity of milk is twice as high as that of water. It increases with the protein coagulation and increasing fat content.

The dimension of the dynamic viscosity is N·s/m or Pa·s; an old term is the centipoise cP (10^{-3} Pa·s). The value for milk at 5 °C is a function of the fat content and ranges from $2.96 \cdot 10^{-3}$ Pa·s (skimmed milk) and $3.25 \cdot 10^{-3}$ Pa·s (whole milk); at 20 °C we observe a range of $1.79 \cdot 10^{-3}$ Pa·s and $2.13 \cdot 10^{-3}$ Pa·s.

2.3.2.8. Surface tension

Surface tension σ [N/m] is often given in dyn/cm (1 dyn/cm = 10 N/m); it is the work W required to recreate a new liquid surface A of 1 cm. In other terms, the surface tension corresponds to a force F which is oriented parallel to the surface, in relation to 1 cm of length l , against which work is to be done when the surface is increased.

$$\sigma = \frac{W}{A} \text{ or } F$$

The surface tension, which causes the contraction of a liquid surface, acts as an interface tension between phase layers (liquid/air, liquid/liquid, liquid/solid). Each phase has its own surface tension, which depends upon the characteristics of the ingredient.

In cleaning processes e.g., the surface tension of the area to be cleaned is reduced, which results in complete wetting of the surface despite the higher surface tension of the water. The surface tension of water is 72.8 dyn/cm at 20°C. Milk and dairy products have a lower value due to fat and protein. Surface tensions for milk and dairy products (all data in dyn/cm) are:

Raw milk	49–51	Cream	42–45
Standardized milk	51	Buttermilk	39–40
Skimmed milk	52–53	Lab whey	51–52

2.3.2.9. Refractive index

When light is projected at a certain angle from an optically thinner into an optically thicker medium, the light is bent at the interface of the media; it is refracted. The refractive index (at a defined temperature exponent 20 = 20 °C and a defined wavelength index D for the wavelength of the sodium spectrum) is a typical characteristic for defining pure liquids.

Water has a refractive index $n_{20}^D = 1.33299$. In aqueous solutions the refractive index increases proportionally as a function of the dissolved compounds. The determination of the refractive index is of technological importance for determining the butterfat content and the lactose content and in the rapid method for determining the dry matter content of skimmed milk concentrate.

2.3.2.10. Electrical conductivity

Due to their ion content, milk is conducting an electrical current. This conductivity κ has the dimension Siemens per meter [$1 \text{ S/m} = 1 / \Omega \cdot \text{m}$] or is given more often in Siemens per cm. The specific conductivity of milk is low ($4 \cdot 10^{-5}$ – $5 \cdot 10^{-5}$ S/cm at 25°C). It is controlled mainly by the levels of sodium and chloride ions; an increase in ions results in a conductivity increase. Udder diseases can be detected by an increase in conductivity of raw milk. The specific conductivity decreases with increasing fat content and thus is suitable for fat content determinations in automated processes.

2.3.2.11. Specific heat capacity

The specific heat capacity c is the quantity of heat which is required to heat 1 kg of material by 1°K ; the units are $\text{J/kg } ^\circ\text{K}$ (an old term is kcal/kg grad). $1 \text{ J/kg } ^\circ\text{K} = 2.389 \cdot 10^{-4} \text{ kcal/kg grad}$. For water we have $c = 4186.8$, for all other materials $c > 4186.8 \text{ J/kg } ^\circ\text{K}$.

The specific heat content of milk depends on temperature and is lower at 40°C than at 15°C . The reason for this is that at 15°C some fatty acids are still crystalline, so that additional heat is required for melting them.

Table 2./9 shows some values for c . Compared to milk, heating of butter requires only half as much heat. Values for the specific heat content are required for energy calculations for the thermal processing of milk (heating/cooling).

Table 2./9 Specific heat c

	Skim milk	Full cream milk	Cream 20% fat	Butter
[$\text{J/kg } ^\circ\text{K}$]	3977.5	3935.6	3516.9	2219.5

2.4. Microbiology of milk

2.4.1. Basics

Milk is an ideal growth medium for microorganisms and contains all nutrient required for their growth.

- Microorganisms or spores are mainly single-cell organisms which are visible as individuals only through a microscope. Among them we find bacteria, yeast and fungi, which are classified in the plant and animal kingdom according to certain characteristics.

We can distinguish the following groups as a function of their reactions and the technological modifications in milk and dairy products:

- a) Technologically useful microorganisms are used in technological processes such as acidification, flavor and gas formation, and protein denaturation (cheese ripening).
- b) Technologically harmful microorganisms cause undesirable changes in technological processes, e.g., milk precipitation, flavor, taste and color changes.
- c) Pathogen microorganisms can cause diseases in macroorganisms (humans, animals, plants) by producing toxins.

Microorganisms are classified systematically in order to identify them properly. Classification is mainly based on their genetic makeup. The most important systematic basic unit of all classification is the species.

- A species is a group of organisms which are similar in all basic characteristics needed for propagation with each other.

The name of a microorganism consist of two words, the genus and the species name, e.g., *Streptococcus lactus*. In the dairy field there are three major groups of microorganisms:

- a) Bacteria propagate by cell fission. Their shape is spherical (cocci), rodlike (with and without spores), and helicoidal. Bacteria, in contrast to fungi, have no nucleus, and their cells are smaller. For a further classification their metabolic products are used, e.g., lactic or acetic acid bacteria.
- b) Yeast propagate by sprouting and normally produce equal amounts of ethanol and carbon dioxide by fermentation.
- c) Molds form an intense mycelium and can be found mostly on the surface of a substrate.

For growth, propagation and metabolism they need—apart from nutrients and water—different environmental factors like temperature, pH and oxygen. Above all, temperature is a controlling factor for their growth. We can distinguish between mesophilic germs (growth range 10–40 °C; they are the most common), the psychrotroph germs (growth range 7 °C and below; in most cases they are technologically undesirable, but can also exist in the mesophilic range) and the thermophilic germs (growth range 35–60 °C; they are used mostly for technological processes).

By reducing the optimal growth temperatures (refrigeration) the growth can be retarded significantly or even stopped. On the other hand, by significantly raising the temperature of the growth range (heating), germs can be inactivated by denaturing their cell substance.

As a function of their relationship to oxygen, we distinguish between obligatory aerobic microorganisms (which can live only in the presence of molecular oxygen) and obligatory anaerobic microorganisms, which live by an internal reaction involving oxidation of substrate (material which permits the growth of organisms) without free oxygen and by liberating energy, e.g., by the transformation of acetaldehyde into lactic acid. Most of the microorganisms can live with and without oxygen and have metabolism. They are therefore called facultative anaerobes.

A further distinction is their method of substrate intake. Those requiring organic substrate are called heterotroph, those requiring inorganic material are called autotrophic. The contamination—or the level of microorganisms in a substrate—is given as cell count per ml or cm³.

- Contamination is the pollution of substrate, cell cultures or organisms but without penetrating into these organisms.

- Recontamination is a retransfer of microorganisms into a sterile or germ-reduced substrate or onto utensils.

The penetration of germs into an organism is called infection. Colloquially, the contamination of milk with microorganisms is called an infection. When microorganisms are inactivated by suitable means or methods so that they cannot cause an infection we call this disinfection (see also Chapter 11).

2.4.2. Microbiological characteristics of raw milk

The microbial content of milk is a major feature in determining its quality. It indicates the hygiene levels during milking, i.e., cleanliness of the milking utensils, proper storage and transport as well as the wholesomeness of the udder of the individual cow.

Microbial levels of milk immediately after leaving the udder are in the range of 100–1000 germs per cm³. The environment (air, feed) contributes about 10,000 germs, and the post-milking installations (insufficiently cleaned milking installations, tanks, pipelines, transport facilities) can contribute ten thousand to millions of germs.

If the milking temperature would be maintained, then we would observe a doubling the germ count within 20–40 min.

In milk we normally find mostly acid-producing streptococci (spherical bacteria, growing in chains) and lactobacilli (rod-shaped lactic acid bacteria). Further we find micrococci, coliform bacteria as well as spore-forming bacilli and clostridia (mainly due to contamination from silage). Due to the chilled storage of milk at 2–4 °C, very often psychrotrophic forms appear, and they can cause negative changes in milk (sensorial defects, chemical degradation) due to propagation and metabolism. Storage temperatures of 8–10 °C are recommended.

Animals with mastitis or other infectious diseases can cause a contamination of milk with pathogens. The most important pathogens are:

Streptococcus mastitis, cause of yellow gait, a sometimes puss secreting mastitis

Mycobacterium tuberculosis, cause of tuberculosis

Bacterium abortus infectiosi, cause of pest like calving (brucellosis)

Typhoid bacteria

Foot and mouth disease virus

Listeria monocytogenes cause of listeriosis

Yesinia enterocolitica and pathogenic *Escherichia coli*

2.4.3. Microbiological cultures

Proper production of dairy products cannot be based on the coincidental presence of desirable microorganism but requires the utilization of special microorganism cultures (cultures, starter cultures or starters).

- Cultures are enrichments on a substrate of microorganisms, which can belong to one or more lines or species. Cultivation is the activity of enrichment.

Each further propagation by inoculation of a defined culture is a subcultivation. A single-line culture is a culture produced from a single cell (clone) by cultivation. Multiple line cultures are derived from several cells (clones). A single-species culture is obtained by combining several single-line and/or multiple-line cultures of a species; multiple-

species cultures are obtained by combination of several species. In the dairy world, multiple-species cultures are called mixed cultures or simply cultures.

The specified culture is produced in special cultivation production units and is sent to the users in the following forms :

- a) Liquid culture—shelf life about 8 days at refrigerated temperatures.
- b) Freeze-dried cultures (dry culture), easily soluble. These are mostly freeze or fluid bed dried, the shelf life is about 5 months.
- c) Deep frozen cultures or culture concentrates, deep frozen at -30 to -35 °C, stored at temperatures of <-25 °C or is frozen at -198 °C with liquid nitrogen, are utilized in the form of pellets with a shelf life of several years at proper storage temperatures.

Utilizing these base cultures in a manufacturing unit can be done in two different ways:

- a) Preparation of a bulk starter, added to milk in levels of 2–6%, mostly with thermophilic acidified products such as yogurt or mesophilic acidification as for quarg products.
- b) Direct inoculation of the processed milk with the original culture, but without intermediary steps (mostly with mesophilic acidification for cheese manufacture).

In processes under a), a mother culture is prepared, which is the base for all cultures utilized in the production process. These cultures can be differentiated into intermediary cultures or process cultures. Intermediary cultures are manufactured from mother cultures and serve as inoculation cultures for production cultures; the latter (process cultures) can be used directly in the production process. Sometimes production cultures are used straight from the mother culture.

Cultures from b) are used as direct starter cultures, also called IFC acidifiers (IFC = inoculum pour cuve de fabrication or “direct to the fat starters”), in form of deep frozen or freeze-dried cultures, which are selected for their specific metabolism (acid production, flavor production, enzymatic reactions).

The types of starter cultures and their utilization in the processing units are shown in Figure 2./9. A schematic of the manufacture of process cultures is shown there.

Groups of microorganisms can be differentiated into bacterial cultures, yeast cultures and fungal cultures as well as mixed cultures. In Overview 2./8 the most important microorganism cultures used in dairies are shown.

The criterion for the selection or utilization of cultures is their performance. This includes all growth activities which produce metabolic changes in milk and dairy products to create desirable, product-specific characteristics but also product defects. The major performance criteria are:

Growth

Glycolysis (breakdown of carbohydrates)

Proteolysis (breakdown of proteins)

Lipolysis (breakdown of fats and fat-like substances)

Gas formation (carbon dioxide and hydrogen)

Flavor formation (desirable and nondesirable)

Inhibitor formation

Through careful selection of the culture, one or several performance parameters can be enhanced. At the same time performance deficiencies with starter cultures can lead to production losses and delays. Causes can be:

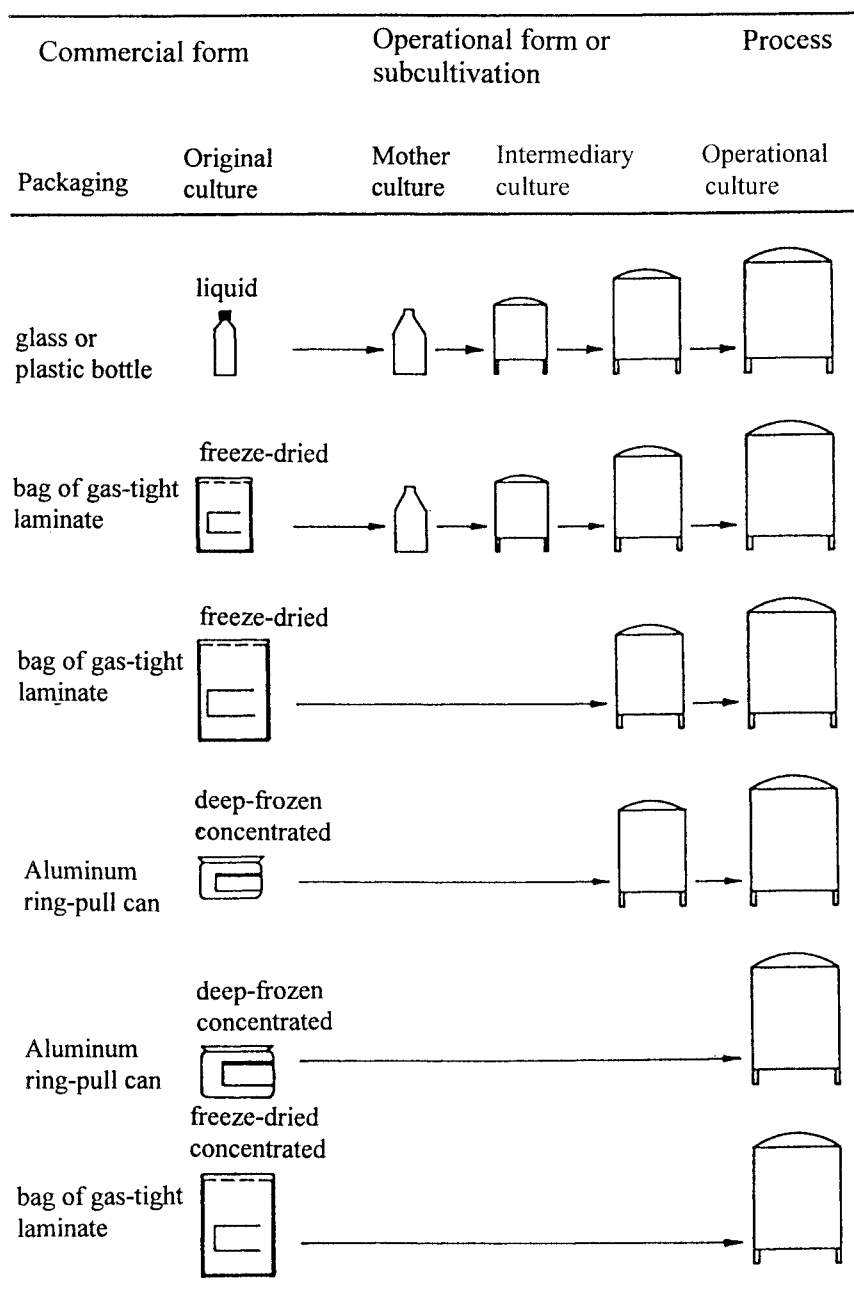


Figure 2./9 Application of starter culture

- a) Deactivation by bacterial phages, i.e., dissolution of bacterial cells by these special viruses of bacteria, also called phages
- b) Deactivation by antibiotics, i.e., antibiotic residues, from treatment of mastitis, passing via the milk
- c) Irreversible loss of basic and technologically important performance parameters of the culture by plasmid losses (i.e., by cultivation at elevated temperatures)

Overview 2./8 Microorganism cultures in the dairy industry

Groups	Species	Optimum temperatures in °C	Utilization
Bacterial cultures			
Mesophilic acidifying	<i>Lactococcus lactis</i> subsp. <i>lactis</i>	28–32	Acidified cream butter
	<i>Lactococcus lactis</i> subsp. <i>cremoris</i>	22–30	lab cheese, fresh cheese
	<i>Lactococcus lactis biovar diacetylactis</i>	28–32	sour milk, butter milk
	<i>Streptococcus durans</i>	18–25	
	<i>Leuconostoc mesenteroides</i> subsp. <i>cremoris</i> (= <i>L. citrovorum</i>)	22–28	
Thermophilic acidifying	<i>Leuconostoc mesenteroides</i> subsp. <i>dextranicum</i>	~25	
	<i>Streptococcus salivarius</i> subsp. <i>thermophilus</i>	38–40	Yogurt, acidophilus
	<i>Lactobacillus delbrueckii</i> subsp. <i>bulgaricus</i>	40–45	milk, Emmenthaler
	<i>Lactobacillus delbrueckii</i> subsp. <i>helveticus</i>	~42	Sour milk quarg
	<i>Lactobacillus delbrueckii</i> subsp. <i>lactis</i>	40–45	
Cheese ripening	<i>Lactobacillus acidophilus</i>	~37	
	<i>Brevibacterium linens</i> (red smear culture)	20–30	Sour milk quarg, diff. lab cheese types,
	<i>Propionibacterium freudenreichii</i>	13–45	Emmenthaler
	<i>Propionibacterium shermanii</i>	13–45	
	<i>Lactobacillus casei</i>	~30	Hard cheese
Mold cultures			
Roquefort	<i>Penicillium roqueforti</i>	~25	Roquefort and similar
	<i>Penicillium glaucum</i>	~25	
Camembert	<i>Penicillium camemberti</i>	20–22	Camembert, Brie
	<i>Penicillium candidum</i>	20–22	soft cheese with old, acidified milk cheese
	<i>Penicillium caseicola</i>	20–22	
	<i>Geotrichium candidum</i> (white mold)	20–22	
Mixed bacteria / mold cultures			
Kefir	<i>Lactobacillus lactis</i> subsp. <i>lactis</i> and/or <i>Lactobacillus lactis</i> subsp. <i>cremoris</i>	18–25	Kefir and similar
	<i>Lactobacillus brevis</i>		
	<i>Candida kefir</i>		
	<i>Kluyveromyces marxianus</i> var. <i>marxianus</i>		
	<i>Debaromyces species</i>		
	<i>Torulopsis species</i>		
	<i>Acetobacter species</i>		

Plasmids are gene carriers which exist with more typical genetic substances, the nucleus or nucleus structures in microorganisms. In bacteria they are the carriers of information related to fermentation of lactose and citrate, proteolysis of β -casein, mucus formation, resistance to antibiotics or phages, formation of bacteriocins (e.g., nisin), and others. Some plasmids can be transferred by contact of the microorganisms among each other and thus can maintain the performance or a culture over years. Controlled transfer is done by genetic engineering.

2.5. Cell count of milk

Significant amounts of somatic cells (somatic: coming from the body) are transferred into milk; they originate from the blood and the uteroepithelium (the top layer in the udder alveolus).

The epithelial cells are formed by continuous natural use and regeneration in the udder. As a normal component of milk, their level in healthy cows is about 60–70% of the total cell count (indicated as cell count per cm^3). Their diameter is about 5–15 μm . The

leucocytes (white blood cells), contributing about 30–40% of the total cell count, perform a protective function in the udder. They encircle penetrated foreign bodies, e.g., infectious germs, and destroy them. A significantly increased cell count is usually due to an infectious change of the udder (secretion disturbance and mastitis). In milk of healthy cows (with a healthy udder), the cell count is in the area of 20,000–400,000 units per cm^3 . At cell levels $> 500,000$ per cm^3 we can assume a secretion disturbance, and once pathogen germs are detected, we can assume mastitis. The cell content in milk gives some clues on the healthiness of the udder of milk cows and the quality of the milk.

2.6. Quality assurance

Quality requirements for processes and products are increasing daily and form a central part of production. They are governed more and more by guidelines, ordinances and laws in states and countries. In Germany, the “Ordinance on hygiene and quality requirements for the production, treatment and distribution of milk” exists, dated June 23, 1989. Also the European Union (EU) issues guidelines and ordinances, which are then adopted into local laws, such as “EU hygiene ordinance for milk and dairy products 92/46/EWG” or the “General food hygiene guideline 93/42/EWG.” Basic guidelines or a “code of principles” for milk and dairy products have been issued through the FAO/WHO food standards program in order to standardize the guidelines and also to protect the consumer. The value perceptions and requirements for products and services are expressed in terms of quality values.

- Quality is the sum of characteristics (composition, grade, capability) of products and services expressing their suitability for a defined utilization. Quality is the result of sociological and scientific-technical work and simultaneously a parameter for their economic efficiency.

In order to ensure the quality of processes and controls for raw materials, finished products, auxiliary materials and additives, basically all activities for quality control including the company’s strategy and documentation for external purposes, quality assurance systems and quality management systems have been developed in companies which correspond to the standards of identity and principles of organization of the internationally accepted quality system DIN/ISO 9000-9004, corresponding to European norms EN 29000 or other accepted systems.

The quality management system of DIN/ISO 9000 has three basic components:

- a) Structural and process organization consisting of
 - Management representative (senior position)
 - Quality representative
 - Job descriptions
 - Responsibilities and functions
- b) Documentation of the system, consisting of
 - Quality management manual
 - Quality management processes
 - Quality management procedures
 - Quality management forms
- c) Proof of the internal audit of the system, consisting of
 - Audit check of a system by an independent third party
 - Audit protocol

- Analysis, list of actions

Once all requirements have been met, a certification is done for each manufacturing unit by an accepted independent institution, usually by an external consultant or specialist. A quality management system governs the corporate philosophy, and at the same time it is an instrument for marketing and consumer information. Quality is the governing factor. The following guidelines exist for quality :

- Top quality of products and services (transport, commerce, customer service) is one of the top objectives of the company.
- The quality objective is always “defect free” or “100% correct”
- The level of quality is set by the customer. The evaluation by the consumer is final. Inquiries, offers or complaints have to be dealt with efficiently. Deadlines must be met.
- All employees of a company—from the apprentice to the managing director—contribute to the realization of the company objectives by working correctly at their work place. When a quality defect is realized, which cannot be solved, the superiors have to be informed immediately.
- All work has to be executed properly from the beginning. To recognize defects and their causes is more important and more economical than to repair them later.
- The achievement of quality standards is an important management tool. The quality of work will therefore be an important factor in employee evaluation.

Manufacturing according to Good Manufacturing Practices (GMP) is one of the quality activities of a QMS.

- The GMP encompasses all activities, leading to the desired product characteristics (sensorial, physical, chemical, microbiological), as well as the sampling plans for the quality control and their legal basis.

An additional quality instrument in a food manufacturing unit is the HACCP (Hazard Analysis and Critical Control Point).

- HACCP is the systematic assurance of the hygienic quality of foods in order to exclude risk to the health of consumers.

Hazards are all characteristics (microbiological; chemical based on residues of chemicals, medicine, toxins; physical based on foreign bodies, e.g., glass or metal particles), leading to a non-acceptable health risk of the consumer. Therefore in an HACCP concept the CCP (Critical Control Points) have to be shown. At a CCP in the food manufacturing process, a health risk for the consumer can be created if this point is not controlled, and a quality defects can occur.

In a dairy plant the following control groups are necessary to ensure the product quality:

- a) Incoming control—all raw materials, auxiliary materials and additives and packaging material.
- b) Process control—all semifinished and finished products as well as additives, support facilities (e.g., brine baths in cheese plants) and production departments must be controlled.

- c) Final control—all finished product must be checked before leaving the plant to ensure that they comply with the quality norms and standards.

The control results must be documented in the corresponding documents, e.g., analytical books. Reference samples and additional samples have to be stored and checked after a defined storage period.

Quality evaluation. Raw materials and finished products are submitted to an organoleptic, chemical-physical and very often microbiological control. Since the products are destined for human consumption, the organoleptic check is of great importance. Results determine the quality in milk and dairy products as well as in all other food.

- Organoleptics refers to determination using trained and tested sensors with methods and under reproducible conditions.

The organoleptic control determines the flavor and taste profile of a food. Flavour characterizes all organoleptic impressions, which are perceived in the mouth and throat area, as well as the texture (see 2.3.2.1). The organoleptic total impression includes:

Gustatory impressions	tasting
Olfactory impressions	smelling/sniffing
Haptic impressions	sensing
Optical impressions	seeing

In organoleptic control we distinguish between the following objectives and methods:

- Differences in individual characteristics (recognition, triangle, threshold test)
- Description of new and unknown products (descriptive control, profile test)
- Control of product quality according to norms, i.e., quality evaluation according to rating/grading (see Overview 2./9)

The organoleptic control is carried out by auditors or experts who evaluate individually or in groups. The following characteristics of a product are considered:

Appearance external	external composition
Appearance internal	internal composition such as consistency, structure, texture, hole formation (e.g. in cheese)
Flavor	aroma, flavor
Taste	flavor, texture

Control guidelines have been established by the corresponding authorities within states (Länder) or central organizations like the DLG (Deutsche Landwirtschafts Gesellschaft). In most cases a point system is applied, whereby the basics of Overview 2./9 are applied either directly or in a modified form. Physical-chemical and microbiological results can be included in this rating system.

Since each parameter does not always have the same value, (e.g., the factor “taste” will always be dominant), weight factors will be utilized. The points achieved during the test are multiplied by the weight factor, and then the sum of the weighted points is divided by the sum of all weight factors. As a result we obtain a quality number < 5. Overview 2./10 shows an evaluation scheme of the Deutsche Landwirtschafts Genossenschaft for

pasteurized milk, where the achieved points are assumed results. This product would have achieved a quality number of 4.5

Overview 2./9 Rating system for a quality evaluation

Points nonweighted	Product characteristics
5	superior characteristics—in complete accordance with quality standards or quality requirements
4	good characteristics—minor deviation from specific characteristics or quality standards
3	slight defects—slight deficiencies or defects
2	noticeable defects—the minimum requirements are not met, but the product still can be consumed
1	serious mistakes—cannot be utilized as originally planned
0	serious deviations from the quality standards

Overview 2./10 DLG evaluation scheme for pasteurized milk

Parameter	Points achieved		Weight factor	=	Weighted rating
Appearance	4	x	4	=	16
Smell	5	x	3	=	15
Taste	4	x	6	=	24
Coliform bacteria	5	x	5	=	25
Total plate count	5	x	2	=	10
Weighted rating			20		90
Quality number	90/20 = 4.5				

State (Länder) regulations govern the number of points per parameter which a specific product is required to achieve. In some states a 20- point system is used for the evaluation of the dairy products, and these products are graded accordingly. The quality evaluation as well as the raw material control of the dairies is done by an appointed neutral organization and chemical laboratories which then inform the dairies about their test results.

Regulations have been established concerning which tests can be done by the dairies themselves and by the testing organizations, which samples have to be taken with what frequency, which sample have to be tested by which methods and whether samples can be stored (and the conditions of storage) or have to be sent to the testing organizations.

2.7. Raw milk

The definition of raw milk is:

- The original milk of one or more cows, which has not been heated to more than 40 °C (original temperature) and has not been submitted to any kind of treatment.

This definition is also valid for milk obtained from goats, sheep or buffaloes. Once a heat treatment occurs, e.g., a thermization (see 2.7.2), the milk is called pretreated milk (see 5.1.1).

2.7.1. Milk formation

Milk synthesis takes place in the udder, which is the milk gland of the cow. The udder is visibly separated into two parts by a longitudinal line and into two more parts by a cross-line, forming four quarters.

The bulk mass is formed by a glandular tissue, surrounded by bands of muscle systems. This tissue consists of multiple glandular alveoles, containing the milk formation cells. In a normal udder the number of these glandular alveoles is estimated to be about 2 billion. Four hundred of these glandular alveoles are the size of a pin prick. Seven to eleven of these glandular alveoles form a gland (see Figure 2./10), connected to the milk channels. They are branched, have bottlenecks and increase in diameter up to 10 mm during their progress toward the udder cistern.

The milk channels end in the udder cistern (which is a cavity), which can collect up to 400 ml. This cavity extends up to the teat cistern. In the lower part of the cistern, is a 1-1.5 cm long channel, and at the end an opening, closed by an annular muscle. This annular muscle prevents the discharge of milk and at the same time the penetration of microorganism from the outside into the udder (see Figure 2./11 for a schematic cross section of the udder).

The entire udder is interspersed with a blood and lymph system, in which the transport of nutrient which is necessary for the milk formation, takes place. The blood capillaries which serve as a connection between the nutrient-rich blood in the arteries and veins, feed the milk formation cells with nutrients. The lymph is a colorless liquid and participates in nutrient exchange where there are no blood vessels.

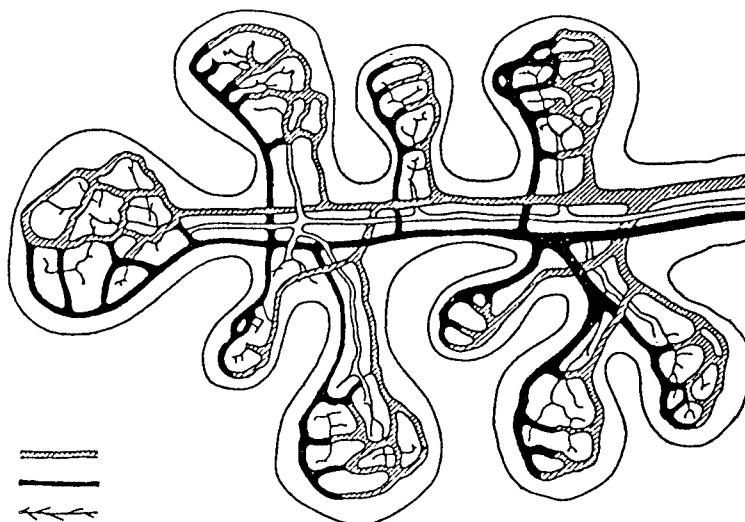


Figure 2./10 Alveole

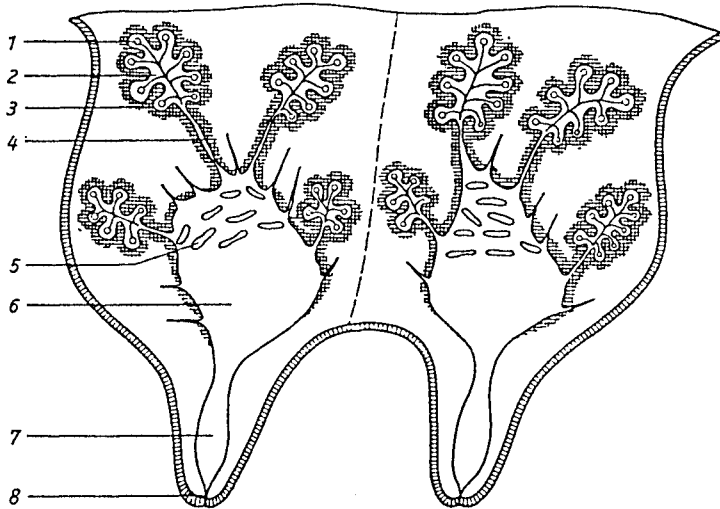


Figure 2./11 Udder cross section

(1) Alveoles (2) Gland (3) Connective tissue (4) Milk channel (5) 10 milk channels for each udder quarter (6) Udder cistern (7) Teat cistern (8) Outlet

Due to the widely dispersed nervous system, the udder is very sensitive to mechanical influences, so that the animal reacts very strongly to improper udder treatment and diseases. This can influence the milk formation significantly.

Milk synthesis takes places in the udder during milking. The milk formation and milk discharge during milking are controlled by hormones via reflex reactions, so that for milking optimal conditions must prevail. This is achieved by “conditioning” the cow. Disturbances in the environment of the animal will lead to a reduction in the milk yield.

Requirements for milk animals. The requirements for animals used for the production of milk as a food is described by ordinances in most of the European countries. In Germany there is the “Ordinance on hygiene and quality standards on the production, treatment and commercialization of milk,” dated June 23, 1989 (and its follow-up versions), in short the “dairy ordinance.” This concerns cows but is applied also to other species of animals (goat, sheep), whose milk is consumed.

According to the dairy ordinance, all milk animals must be free of tuberculosis and brucellosis, and they should not show any signs of infectious diseases which can be transmitted to humans. The overall health level must be acceptable. Cows have to yield at least 2 liters per day in order to be labeled milk cows.

2.7.2. Milk production

The production of milk is called milking.

- Milking is the discharge of milk from the udder either manually or mechanically, wherein the pressure effects (suckling) of the newborn calve are imitated. Milking

must be done in such a way, that the udder remains healthy, and milk is not influenced negatively.

Minimum standards have been established for the milking process, the rooms where it is done, to the persons doing the milking.

The milking process is preceded by a cleaning and massage of the udder. The first jets of milk usually have a high bacterial load; therefore they have to be separated from each tit and are put into a separate container (foremilk vessel). Thereafter the correct quality of the milk must be checked by visual inspection.

At the end of the milking process, a postmilking takes place either by massage or by a change of the pulse frequency, which leads to a milk very high in fat. Milk remaining in the udder not only means a production loss but can also lead to udder infections.

Milking personnel. No person having transmittable diseases can be employed for milking. The personnel must have clean, easy-to-wash uniforms and head covers. Before the milking and also during milking, hands and arms must be cleaned with water and a cleaning agent.

2.7.3. Raw milk quality

2.7.3.1. Quality characteristics

Good raw milk quality is the basis for the production of high quality dairy products. The raw milk quality is controlled by the following characteristics:

- a) Level of nutrients and reagents
- b) Chemical-physical characteristics
- c) Level of total plate count and composition of the flora, e.g. level of spore formers, coliforms, psychrotrophs and thermoresistant microorganisms in the total plate count as well as level of somatic cells (cell count)
- d) Presence or absence of pathogenic organisms such as those that cause tuberculosis, brucellosis or mastitis
- e) Presence or absence of diseases such as pus particles or toxins
- f) Presence or absence of deleterious substances such as inhibitors or other foreign substances (see Overview 2./6)
- g) Taste and flavor
- h) Cleanliness of milk

2.7.3.2. Quality requirements

Apart from the expectation that the raw milk complies with the general standards, the law has promulgated standards which result in a quality reduction when the milk does not comply with these standards and can even prohibit commercialization of the milk; at the very least a price reduction can result.

In the EU countries, quality standards have been issued under “Guideline 92/46/EWG for hygiene requirements for the production and commercialization of raw milk, heat treated milk and dairy-based products” which have been adopted as local standards by the member countries and are considered local law. The following quality characteristics have been set for raw milk:

- a) Fat content in %
- b) Protein content in %
- c) Microbial or bacteriological levels in units/cm³
- d) Cell count in units per cm³
- e) Freezing point in °C
- f) Inhibitors as antibiotics (penicillin) in mg/cm³

In addition, the frequency of analysis per month is determined, sometimes related to the quantity of milk. The geometric average of the number of analysis is formed. For example, the average plate count from three samples is calculated as follows:

$$\text{average plate count} = \sqrt[3]{\text{value 1} \times \text{value 2} \times \text{value 3}}$$

According to the results, the raw milk is graded. A base price is allocated to a standard quality, and bonuses and deductions are then calculated. Overview 2./11 shows the results. Compliance with the norms is controlled by random sampling on the farm as well as at the manufacturing plant level. A basic factor is that the milk has been produced on farms free from tuberculosis and brucellosis.

2.7.3.3. Quality influences

Special emphasis should be placed on the production of milk and its treatment, since they can be influenced daily in a subjective way. Milk must be removed immediately from the shed, must be cleaned with suitable filters (see Figure 2./12) and must be placed in a location, which is equipped to avoid any negative influences. Simultaneously it must be chilled.

- If milk is not collected within 2 hours, it needs to be chilled to < 8 °C for a daily collection or to < 6 °C for a longer storage period.

As contaminating organisms go through a lag period in freshly milked milk and the growth and propagation are very low, the organisms' multiplication can be reduced significantly by immediate chilling. The microbial development in insufficiently chilled milk is shown in Figure 2./13 and the required equipment is shown in Figures 2./14 and 2./15.

During chilling, although the growth and propagation of mesophilic lactic acid bacteria are reduced, psychrotrophic bacteria (e.g., gram-negative species such as *Pseudomonas*, *Alcaligenes*, and *Acinetobacter* as well as gram-positives like micrococci, microbacteria and some bacilli) can develop very rapidly. These bacterial groups can break down lactose, protein and fat in milk, and some of them produce thermoresistant enzymes such as proteolytic and lipolytic enzymes. These result in significant quality deterioration in raw milk.

For several, mainly logistical reasons, when a short storage period cannot always be maintained, mild heating of the milk, so-called thermization, can reduce quality losses. This milk is then termed treated milk or thermized milk.

- Thermization of raw milk refers to heating with continuous flow to 57–68 °C with an effective holding time of min. 15 s and max. 30 s; (see also Overview 4./4).

Raw milk must be clarified before thermization. After thermization, the milk is chilled once again and can be stored for several days without any microbiological negative ef-

fects. Thermization is usually done in a dairy for technological reasons, usually immediately after reception. It is rarely done on the farm.

Overview 2./11 Quality requirements for raw milk

Quality characteristics	Requirements for the production of:				
	Heat-treated market milk	Fermented milk, Milk with rennet, Coagulated milk, Flavored milk, Cream	Products other than those mentioned in columns 2 and 3 (e.g., cheese, butter, milk powder)	Raw cow milk (for the manufacture of raw milk products without heat treatment)	
			until 12/31/97	from 1/1/98	
(1)	(2)	(3)	(4)	(5)	(6)
Plate count at 30°C per ml ¹	≤100,000	≤100,000	≤400,000	≤100,000	≤100,000
Somatic cell count per ml ²	≤400,000	≤400,000	≤500,000	≤400,000	≤400,000
Freezing point in °C	-0.520 or lower				
Spec. density at 20°C per ml	>1028				
Protein in g/l	≥28				
Fat-free dry matter in %	≥8.5				
<i>Staph. aureus</i>	absent				n=5, m=500 M=2000 c=0

¹ Geometric mean over 2 months with a minimum of two samples per month.

² Geometric mean over 3 months with a minimum of one sample per month.

n = number of samples; m = threshold value for the microorganism count; M = maximum value for the microorganism count; the test is unsatisfactory if one or more samples have a value equal to or more than M; c = number of samples with a count between "m" and "M"; the test is acceptable if the microorganism count of the other samples is not more than m.

In countries with a low raw milk quality, due to insufficient production, chilling and storage methods, an alternative method is applied. This involves the addition of lactoperoxidase/thiocyanate/hydrogenperoxide; by minute additions of thiocyanate (10 mg/kg) and hydrogenperoxide (8–9 mg/kg), which result in a lowering of the bacterial load. This process, however, needs an official approval.

Raw milk must be stored until the dispatch in a well-aerated storage room in tanks or other vessels (covered) with a stirrer. During this storage the milk has to be stirred several times; otherwise the degassing of the milk is made more difficult by the formation of a fat layer, resulting finally in an acidification and taste defects. The storage and transport vessels should only be used for milk. Raw milk quality is influenced on the farm by the following factors:

- a) Feeding and maintenance of the milk animals
- b) Health of the milk animals
- c) Milking process and treatment

Overview 2./12 shows the consequences of defects in these areas.

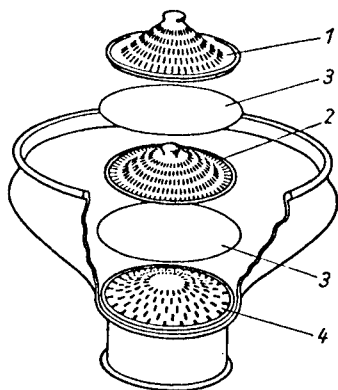


Figure 2./12 Milk filter (detail)

(1) Impact sieve (2) Upper sieve (3) Cotton filter (4) Inner sieve

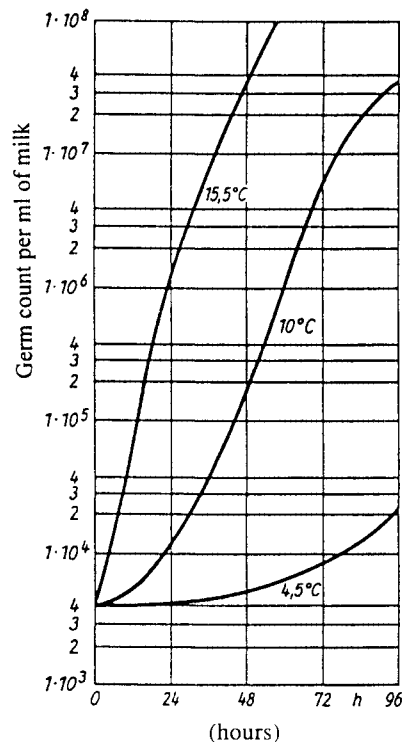


Figure 2./13 Bacterial growth in milk in function of chilling temperature and time (Tuschneid-Emblik)

Basic technologies used for milk treatment and storage (as shown in Figure 2./16) depend on the quantities involved. Technology I is based on a continuously available milk flow. Filter and plate heat exchangers are included in the vacuum system of the milking facility, so that milk is transferred into a collecting vessel via a relief valve. In technology II, the relief valve of the milk pipeline is situated on top of a balance. After determining the quantity, the milk is pumped into a chilling container for chilling and storage. Technology III operates in a similar way, but the milk is chilled rapidly in a plate heat exchanger and is then transferred into an insulated tank until dispatch. For technologies II

and III, continuous milk flow is not necessary. These technologies are suited for collecting stations, where milk from several farms or suppliers is collected, chilled and stored.

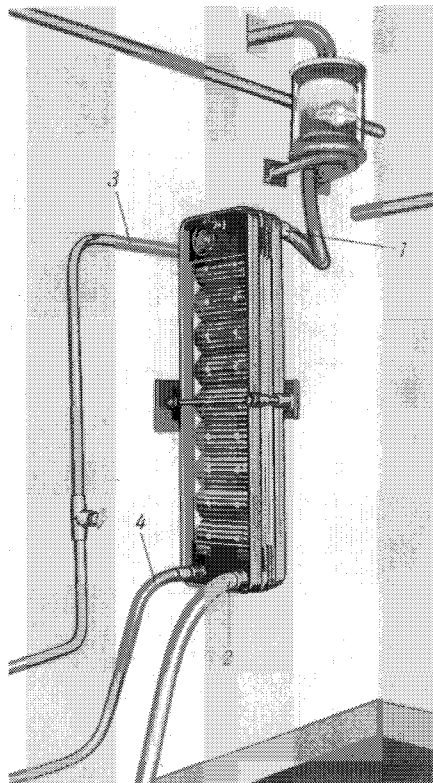


Figure 2./14 Plate heat exchanger raw milk type PA 400/901
(1) Milk inlet (2) Milk outlet (3) Chilled water inlet (4) Chilled water outlet

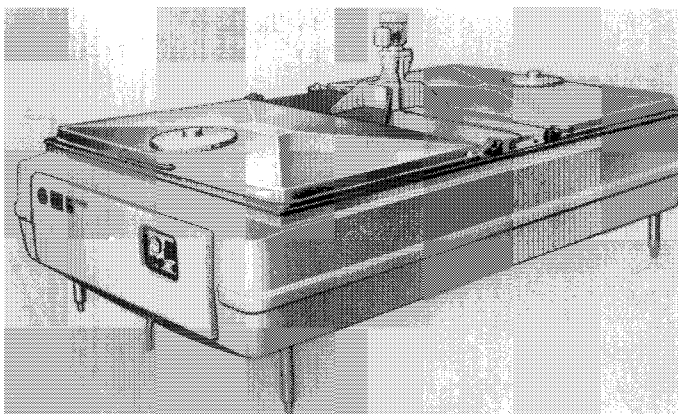
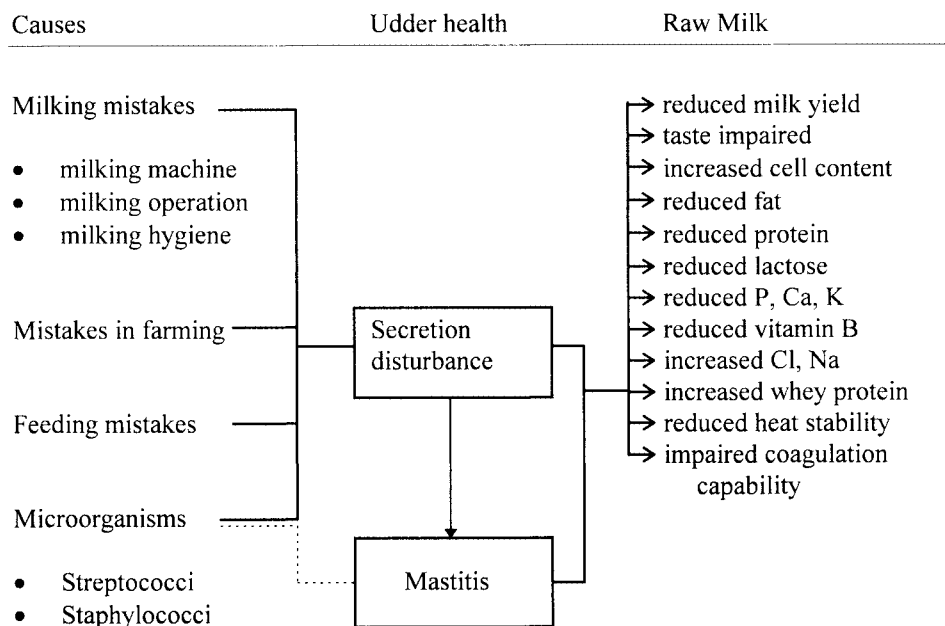


Figure 2./15 Milk cooling tank, type MKA 2000 L-2

Overview 2./12 Changes in raw milk quality and quantity as well as their causes ¹



¹ Source Frank, W.: Der amtlich anerkannte Eutergesundheitsdienst, Welt der Milch, 16, (1976).

2.7.4. Raw milk collection

The dairy plans and organizes the collection and transport of milk in its collection area. Route plans need to be established and are continuously optimized for an optimal utilization of the transport facilities and keeping transport costs low.

According to the structure, extent and distances of the collection area, the form of collection and transport is selected. Normally we find two forms in raw milk collection:

- a) Collection and direct transport to the dairy
- b) Collection at collection points, then transport to the dairy

Collection through collection points is done mostly in areas with a large number of small suppliers and thus eliminates a need for their own chilling and storage facilities. Collection points must comply with the same hygienic requirements as the dairies. Facilities for determining the quantities, sampling, chilling and storage must be available. Sometimes a thermization unit for the raw milk is installed.

Transport facilities. Transport facilities are selected on the basis of the raw milk collection as well as regional requirements. These include:

- a) Milk churns with a capacity of 20 l, sometimes 10 l, made of stainless steel or aluminum., with a lid design avoiding collection of water and an ensuing hygienic risk to the contents
- b) farm containers of 20–200 l, made of stainless steel, mobile and insulated (partially with chilling)

- c) Tanks installed on trucks with a capacity of 600–3000 l, sometimes with a direct connection to the milking facility
- d) Milk tankers with a capacity of 9000–30,000 l, separated into several chambers (see Figure 2./17) with an integrated reception device and data recording (see Figure 3./1)
- e) Transfer pipes

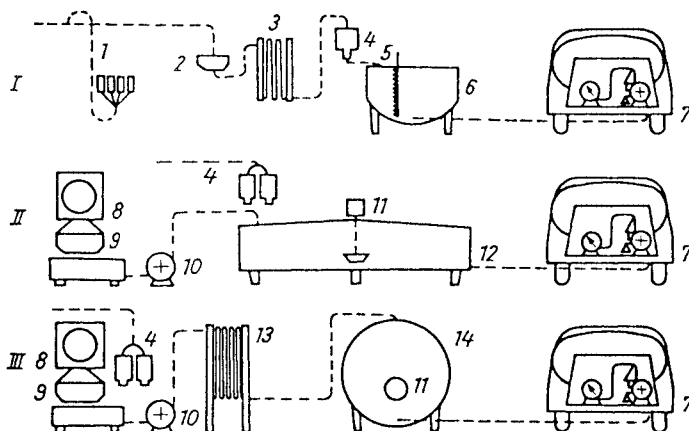


Figure 2./16 Basic technologies for raw milk treatment and storage

(1) Milking machine (2) Vacuum system with filter (3) Plate heat exchanger, flow ca. 500 l/h (4) Relief valve (5) Gauge (6) Insulated tank (7) Milk tanker (8) Milk balance (9) Balance container (10) Milk transfer pump (11) Stirrer (12) Storage container for chilling (13) Plate heat exchanger, flow ca. 1000 l/h (14) Insulated milk storage tank

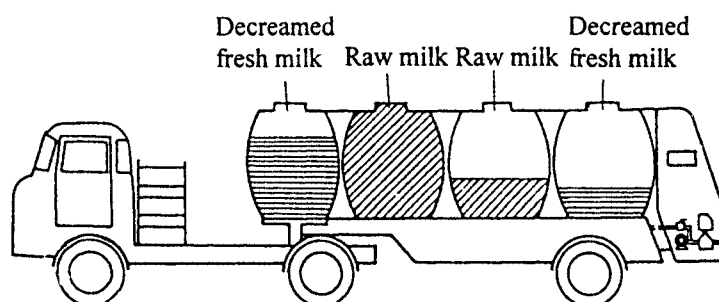


Figure 2./17 Milk tanker with four chambers made of stainless steel or aluminum with integrated transfer, measuring and sampling facility; suited for milk collection and simultaneous return of skimmed milk to the producer.

All transport vessels must comply with the hygienic requirements, especially with requirements such as:

- a) The inner surface and all other parts in contact with milk must be of a smooth material, corrosion free, easy to clean and disinfect and nonreacting with milk, which

would resulting in risk to the consumer or negatively influencing the quality of the milk or its organoleptic characteristics

- b) The milk must be emptied completely; the container is equipped with valves which can be easily dismantled, cleaned and disinfected
- c) After each use and sometimes before reuse the container has to be cleaned and disinfected immediately, this must be done at least once per working day
- d) Before transporting the milk, the container has to be closed properly, so that no milk can be drained, and the closure remains tight during the transport.

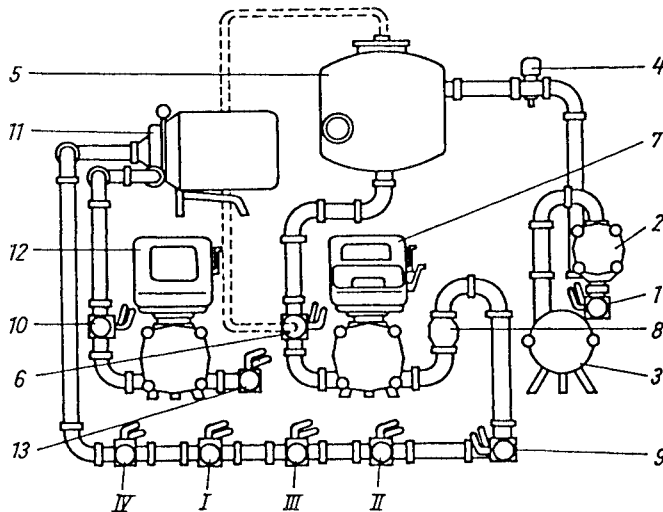


Figure 2./18 Plan of the transfer, sampling and measuring device of a milk tanker

(1) Raw milk reception valve (2) Filter (3) Transfer pump (4) Automatically controlled sampling valve (for ratios 1:5000, 1:10000 or 1:20000 with a selector) (5) Degassing (6) Valve for pipeline discharge (7) Flowmeter with printer (8) Nonreturn valve, eliminating the flowback of milk from the tank (9) and (10) Valve for raw milk reception in dairy (11) Milk transfer pump of skimmed return on producer's site or raw milk reception in dairy (12) Measuring device for skimmed milk leftovers (13) Skim milk return valves I, II, III and IV, connection valves for milk tanks.

Transport of churns is very expensive and is rare today. Areas with small mostly have farm tanks which permit the transport of milk to the collecting point or collecting facility.

Milk tankers are the most prevalent transport system, not only because of a cost-effective transport of bulk quantities of milk, but also because it permits the integration of transfer, sampling and measuring devices (see Figure 2./18).

For milk transport between the dairy and the collecting points, subterranean pipelines can also be used. Milk is pumped or is flowing by gravity if the location is suitable.

3 Milk Reception

3.1. Quantity determination

3.2. Quality evaluation

3.3. Cleaning and disinfection of transport facilities

3.4. Milk returns

3.5. Process for reception and returns



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3 Milk Reception

- Milk reception or milk delivery refers to the accepted transfer of raw milk from the farm by a dairy.

This transfer is done with milk tankers (see Figure 2./18), at collection points in the dairy or usually in a separate section of the dairy. In the reception section, the tankers (or the churns) are discharged and the transport facilities are cleaned.

Milk reception consists of three basic processes:

- a) Determination of the raw milk quantity
- b) Evaluation of the raw milk quality
- c) Cleaning and disinfection of the transport facilities

3.1. Quantity determination

- For each supplier the quantity of raw milk delivered has to be determined in kg.

The quantity determination is the basis of the payment to the supplier and of the determination of the total mass, the quantity balance and the production planning of a dairy. The quantity is determined either directly with a balance or indirectly by volume.

Weighing. Special milk balances (see Figure 3.1) are used, with which the mass of milk (stored in a special container) can be read and registered in kg (weighing precision is 1 kg). The data can then be transferred to a computer or to a central data processing unit. Although the mass can be obtained very precisely by direct weighing, a continuous process is not possible due to the alternate filling of the weighing container. A continuous flow measurement is therefore preferred.

Volume measurement. Here the milk is measured in flowmeters in a continuous flow. The volume determined in dm³ or liters is then converted to mass according to the formula

$$m = V \cdot \rho$$

m mass in kg

V volume in dm³ or l

ρ density in kg/l (for raw milk 1.03 kg/l can be used)

Metering devices. Three basic devices are used—ring piston counter, lobe piston counter and the magnetic-inductive flowmeter.

With the ring piston counter, the casing is defined as the measuring chamber with a precisely defined volume, in which a ring piston with a precisely defined volume transfers the liquid by rotation from the inlet to the outlet (see Figure 3./2).

The lobe piston counter is based on a similar principle (Figure 3./3). The measuring chamber, which is pressure tight and made of stainless steel, houses two lobes. The volume determination is done by the displacement of precisely defined volumes which are created by the rotation of the lobes. They are driven by the pressure of the flowing liquid. With each rotation, a liquid volume, corresponding to the volume of the measuring chamber, flows through the counter (Figure 3./4). The liquid volume is proportional to the lobe rotation and is shown by an indicator device.

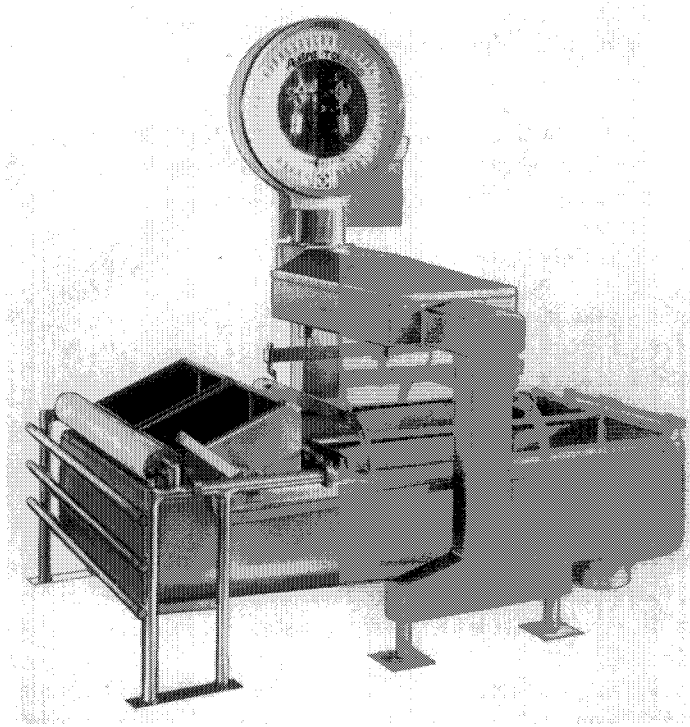


Figure 3/1 Milk balance with indicator

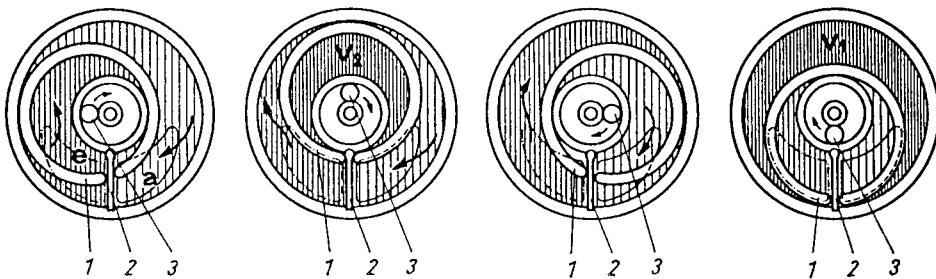


Figure 3/2 Measuring chamber of a ring piston counter: $V_1 = V_2$

e) Inlet a) Outlet

(1) Piston (2) Separation wall (3) Piston stopper

These volume measurements have inherent measuring defects when air is in the milk, as its volume is also measured.

- In volume measurement, the milk needs to be free of air when it passes through the flowmeter. A properly functioning deaeration unit must be installed before the flowmeter.

The basic principle of magnetic-inductive flowmeters (Figure 3.5) is the Faraday induction law.

$$U = B \cdot l \cdot v$$

U induced current

B strength of the magnetic field

l pipeline diameter or electrode distance

v flow velocity

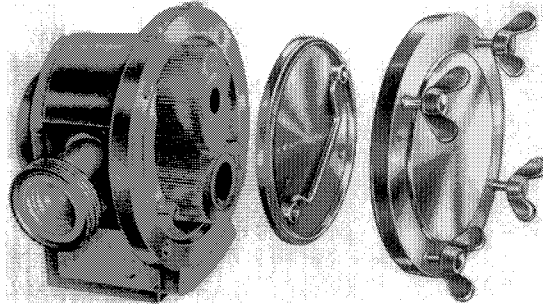


Figure 3/3 Lobe piston counter assembly

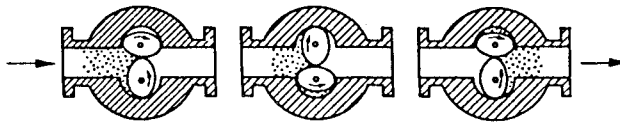


Figure 3/4 Phases of volume displacement in a lobe piston counter

An artificial magnetic field is created in a Teflon-covered pipe having the same dimensions as the connecting pipes. A current U is created between the electrodes facing each other which is proportional to the flow velocity v , induction B and the electrode distance l . When induction and electrode distances are equal, then we have

$$v = \frac{\text{flow volume } V}{\text{Cross-section } A} = \frac{4 \times A}{p \times d^2}$$

resulting in the flow volume

$$V = \frac{U \times d \times p^2}{4 \times B \times l}$$

U voltage

l pipeline diameter

The advantage of this method is easy manipulation, especially during dismantling, cleaning and sterilization. The methods described above are the prevalent methods used in dairies.

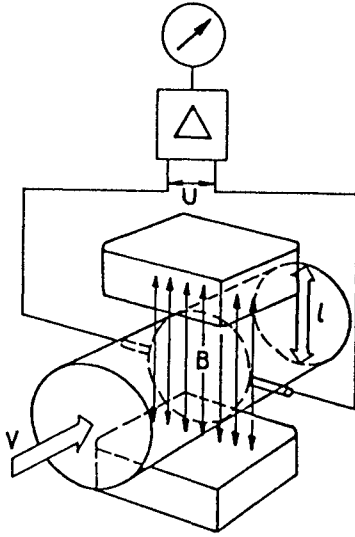


Figure 3./5
Principle of a magnetic-inductive flowmeter

Milk data collection systems. In many milk tankers, electronic systems are used that permit high reliability and precision for data monitoring and further data processing. Supplier and route number, quantity in liters, temperature and pH are determined automatically and control the sampling. Data are shown in digital form and are recorded on a cassette. An additional printer makes a printout and can serve as a receipt for the supplier. The various data processing methods are shown in Figure 3./6

Fat determination—fat units. Milk fat is a determining quality factor. It is a key factor when the milk price and the price of the finished product are determined. The quantity of fat in raw milk or in many other dairy products cannot be determined by simple weighing, since it exists mostly in the form of an emulsion and cannot be separated in its pure form. Therefore the fat percentage is determined, which then permits the calculation of the fat units.

$$1 \text{ fat unit} = 10 \text{ g pure milk fat}$$

Fat units are calculated according to the formula

$$FU = m \cdot f$$

FU fat units (no dimension)

m mass of milk or fat-containing substance

f fat content (%)

With the fat units, the average fat content f_g of several milk quantities with different levels can be calculated by determining the sublots' fat units and then calculate the sum of the fat units FU_{total} and masses m_{total} . We then calculate according to the formula

$$f_g = \frac{FU_{total}}{m_{total}}$$

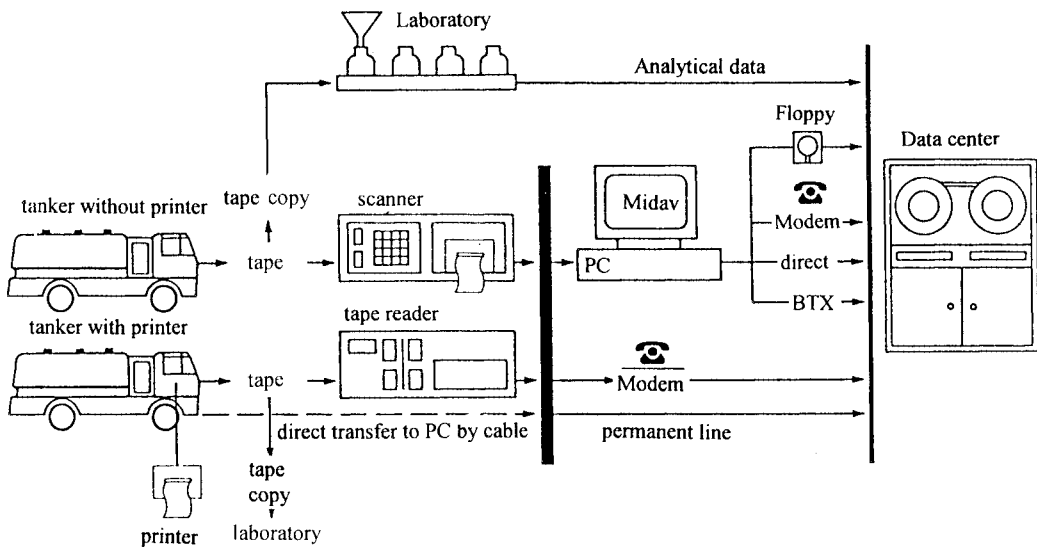


Figure 3./6 Possibilities for data processing in raw milk reception

In addition, this permits us to calculate the equivalent quantities of other types of fats (base fat content) whenever necessary. In general and for statistical comparative purposes (if raw milk is assumed to have a fat content of 3.7%), then raw milk with more or less than 3.7% fat content can be calculated. This requires the milk quantity, the fat units, and the base fat content (set at 3.7%).

Protein content. The protein content is determined in a similar way to the fat content, according to the relationship:

$$PU = m \times p$$

PU protein units
m milk quantity
p protein content in %

3.2. Quality evaluation

Some aspects of the quality evaluation of raw milk have been dealt with in Section 2.7.3. The purpose of the quality evaluation is:

- Control for commercialization purposes, i.e., to see if the general hygiene standards in production and composition are met
- Rejection of spoiled or milk with other defects¹
- Classification of milk as a basis for payment and further utilization
- Selection of milk for culture preparation and production of specific products

In Germany this evaluation is done according to the Milchgüteverordnung MGVO (ordinance on milk quality) using organoleptic, chemical-physical and microbiological-cytological parameters.

¹ Defects of the milk which can be noticed organoleptically, especially visually.

Organoleptic evaluation. This control is not mandatory according to the MGVO. However, a visual and flavor control on a random basis is recommended. In cases of doubt or for milk with higher quality requirements, such as for cheese, a taste control is performed.

Chemical-physical and microbiological-cytological control. Dairies must control the delivered milk according to the MGVO for each supplier on the basis of quality. These controls are done by control associations, such as the dairy control circle, which then distribute the results. The quality parameters are shown in 2.7.3.2. The first check on milk is done for inhibitors (see 2.3.1.9).

Sampling. This is done from the tanks or by automatic sampling devices, whenever churns are supplied, or from the weighing container. A sample quantity is taken, which is representative of the milk, and which permits the minimum number of analysis to be performed.

In general, the milk tanker collects an aliquot sample for the supplier, which is then properly mixed and transferred to a sampling bottle. This bottle already contains a preservative to inhibit the growth of germs. Samples have to be stored at temperatures $<10^{\circ}\text{C}$, which have to be maintained until the analysis.

For the monthly freezing point determination, a nonpreserved sample must be taken in order to exclude perturbation of the analytical results by preservatives. The required milk qualities are shown in Section 2.7.3.

3.3. Cleaning and disinfection of transport facilities

After discharge, the raw milk transport facilities have to be cleaned and disinfected at least once per day. Milk which adheres to the inner tank surfaces decomposes very rapidly, influencing later milk negatively. Further, a multitude of microorganisms has to be foreseen, some of which are pathogenic.

Churn cleaning. Churn cleaning is done in tunnel washing machines, similarly to the cleaning of crates for bottles or one-way packing units. As a cleaning medium, an aqueous alkaline solution with concentrations of 0.5–2.5% is used. The working principle of these washing machines is that the churns are transported through the tunnel by way of a continuous chain, held at an angle through the spray tunnel and submitted to the effects of temperature, concentration and flow (see Figure 3./7). The cleaning solution and the hot water are recirculated.

Residues of milk (after discharge) are labeled “drop milk.” Due to its high bacterial load, this milk is boiled, colorants are added, the milk is properly labeled, and the milk is used in the animal feed industry.

Tank cleaning. Cleaning tanks is done by prerinsing with fresh water, followed by steaming, or it can be done by tank cleaning and disinfection installations.

The installation (Figure 3./8) works as follows: manual prerinsing with water of $\sim 30^{\circ}\text{C}$ (in order to eliminate the bulk residues of milk) is followed by connecting flexible pipes to a tank cleaning device. A rotating spray nozzle device, inserted into the tank through the manhole, sprays the cleaning and disinfection solution at pressures up to 40 bar. This spray has a mechanical and chemical cleaning effect on the inner surfaces of the tank. A flexible hose returns the solution to the preparation tank. Temperature, concentration and dirt are controlled and when necessary, compensated for. The duration of the process (normally 10–15 min) can be used to control the cleaning and disinfection efficiency.

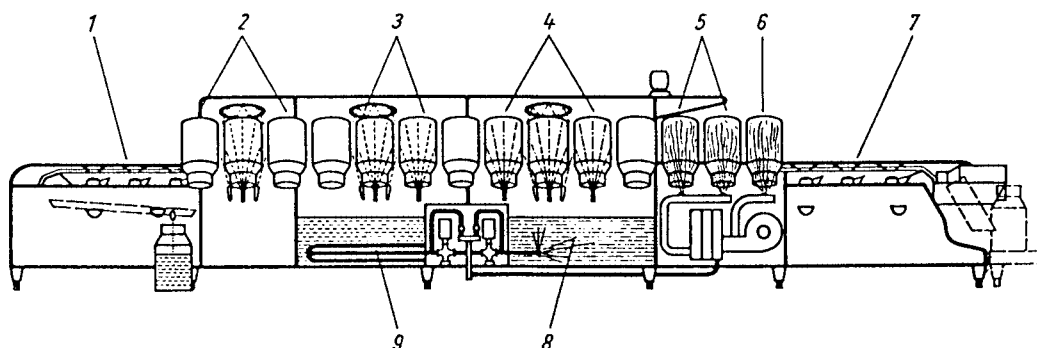


Figure 3.7 Cross section of a churn washing machine, type MKW 550, capacity 550 churns per hour, steam consumption 225 kg/h, electricity consumption 8 kWh
 (1) Milk reception section collecting device for milk (2) Prerinsing with fresh water up to 35 °C, 1.2–2 bar (3) Lye spraying 65 °C, 3.4 bar (4) Hot water spraying 85 °C, 3.4 bar (5) Hot air (6) Cold air (7) Discharge section with churn turning device (8) Hot water tank (9) Lye tank

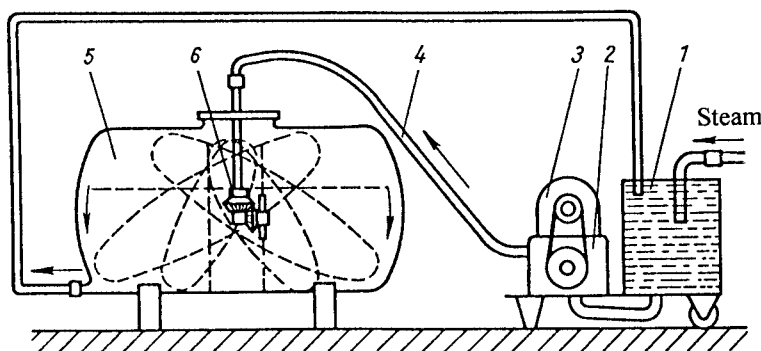


Figure 3.8 Plan of a tank cleaning installation

(1) Preparation tank for cleaning solutions (2) Transfer pump for cleaning solutions (3) Pump motor (4) Flexible pipe (5) Milk tank (6) Rotary spray nozzle

For cleaning underground pipelines, a far lower temperature for the cleaning solutions (< 40 °C) is used. This is due partly to the plastic material, which is sensitive to heat, and also to the heat lost to the surrounding environment. Cleaning and disinfection solutions must meet strict requirements.

3.4. Milk returns

In the context of milk reception milk returns also take place.

- Milk return is the return of milk treated by the dairy to the farm for feeding purposes.

Milk return in this context is not the dispatch of milk and dairy products to wholesalers and retail institutions. This activity would be labeled dispatch or expedition. From an economic point of view returns do not make much sense, as an added-value product is used for animal feeding in order to begin a new processing cycle. The exception is milk used for calfrearing. Another reason for returns can to reduce seasonal oversupplies.

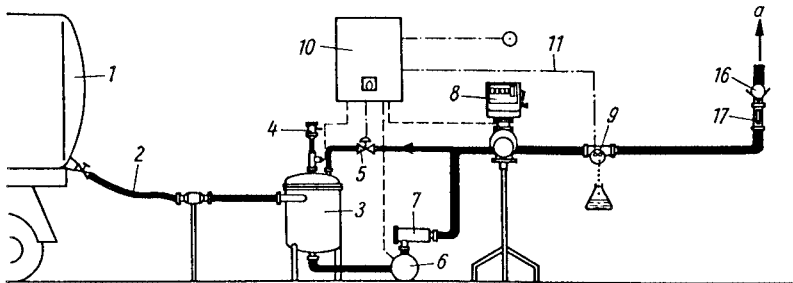
- All return products should be put into sufficiently cleaned and disinfected transport facilities.

3.5. Procedures for reception and returns

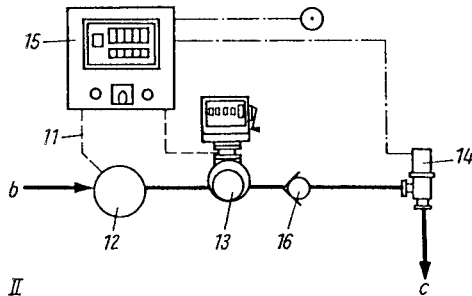
The type of processing line equipment used is based on the daily milk quantities and the type of delivery. In plants with tank and churn reception, both types of processing lines are sometimes combined. As an example, the process scheme for tanker reception and return is shown in Figure 3./9.

After opening the transport tank (1) and thorough mixing of the milk, temperature and acidity are determined. Milk is then transferred via a flexible hose (2) to a deaerator (3). Once the level controller (4) indicates a sufficiently high liquid level to the controlling unit (10), which guarantees sufficient deaeration, the transfer pump (6) pumps milk through a tubular sieve (7) to the counter (8). Data can be read directly and are then transferred to the data processing unit. The automatic sampler (9) takes the required sample for acceptance control; the milk passes a show glass (17) and a nonreturn valve (16) and enters the silo. If the liquid level is reduced to less than preset minimum in the deaerator, the milk passes through a valve (5) into the flowmeter.

After cleaning and disinfection of the tanker, unit II transfers the return milk to the tanker. The quantity is preset in a dosing device (15) using a pump (12); milk passes a flowmeter (13), a nonreturn valve (16), a control valve (14) and goes into the tanker. Once the preset quantity has been dosed, the control valve (14) interrupts the milk flow, and the filled quantity can be read from the flowmeter (13).



I



II

Figure 3./9 Flowsheet for milk reception and return

I, reception; II, return

a) Raw milk to storage b) Skim milk from storage c) Skim milk to milk tanker

- (1) Milk tanker (2) Flexible pipe (3) Deaerator (4) Level controller (5) Control valve for raw milk return to deaerator (6) Pump (7) Tubular sieve (8) Meter (9) Automatic sampling device (10) Control panel (11) Control pipelines (12) Pump (13) Meter (14) Two-way valve (15) Control panel for metering (16) Nonreturn valves (17) Show glass



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4 Milk Processing

4.1. Terms and definitions

4.2. Technology

4.3. Process lines

4.4. Dairy equipment



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4. Milk Processing

4.1. Terms and definitions

- Milk treatment is the preparation of raw milk, including heat treatment as a precondition for milk processing.

The treatment of milk is done in the preparation room. It is a basic process in each dairy plant, as all of the milk is submitted to this technological process.

On the one hand, legally defined hygienic requirements must be met (such as heat treatment); on the other hand, milk is prepared as a function of the final process utilization. The type and intensity of the treatment are selected accordingly.

The process can be carried out to such a level that for, e.g., pasteurized milk the required final quality can be nearly achieved. Treatment then becomes processing.

- Milk processing is the quality-oriented activity of manufacturing and packing of dairy and dairy-based products on the basis of treated milk.

In the section on milk processing, all process activities and steps as well as the required machines, instruments and lines as well as their technology are dealt with in detail. Furthermore, we look into the basics of material requirements, machine elements, pipelines, instruments and pumps which are used in dairies.

4.2. Technology

The basic flowsheet for dairy technology is shown in Overview 4./1. Here we see that homogenization is not always a part of the treatment; it is used only when it is advantageous for further processing. Storage of milk is mostly separate from the processing section and is therefore not part of the treatment.

4.2.1. Raw milk storage

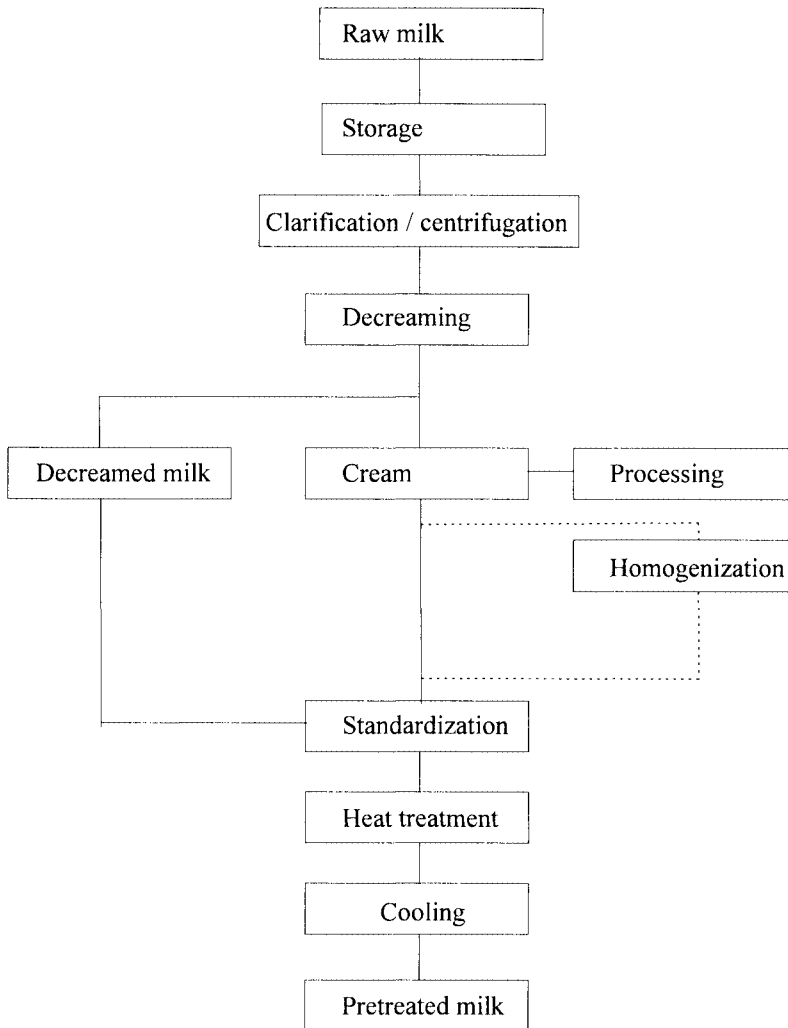
- Storage is an activity in which milk is kept between reception and processing.

Storage helps in balancing the different capacities and timings between reception and processing, which are independent activities. This becomes necessary, especially when milk reception is on a 24 hour basis or when milk reception takes place within a short time, all in function of the optimal utilization of the milk tankers.

The total volumes of the storage silos can be very different and can vary from 20 to 100% of the daily reception volume. Usually storage vessels (or silos) are installed individually on the outside of the building(s), are made of stainless steel or fiberglass (Figure 4./1), and can have a volume of 20,000–2,000,000 l. They are equipped with a stirring system and a facility for chemical cleaning (CIP, clean-in-place).

Before the milk enters a silo, it can, if necessary, be passed through a plate heat exchanger in order to reach a storage temperature of ≤ 6 °C. During storage the milk must be stirred several times in order to avoid destabilization of the fat distribution by creaming and to maintain a constant temperature.

Overview 4/1 Basic flowsheet of milk treatment



Stirring with too high mechanical stress can result in significant defects in the milk, especially the milk fat; this is the case when air is incorporated into the milk.

- During storage, milk should be stirred in such a way as to avoid creaming of the fat. Stirring should begin only when the stirrer wings are completely covered by milk.

4.2.2. Raw milk clarification

4.2.2.1. Purpose and meaning

The purpose of clarification is to remove from the milk all foreign material (which may have entered milk during milking, treatment or transport). This process removes organic and inorganic material (animal hair, dust particles etc.), somatic cells as well as microorganisms and their protein agglomerates.

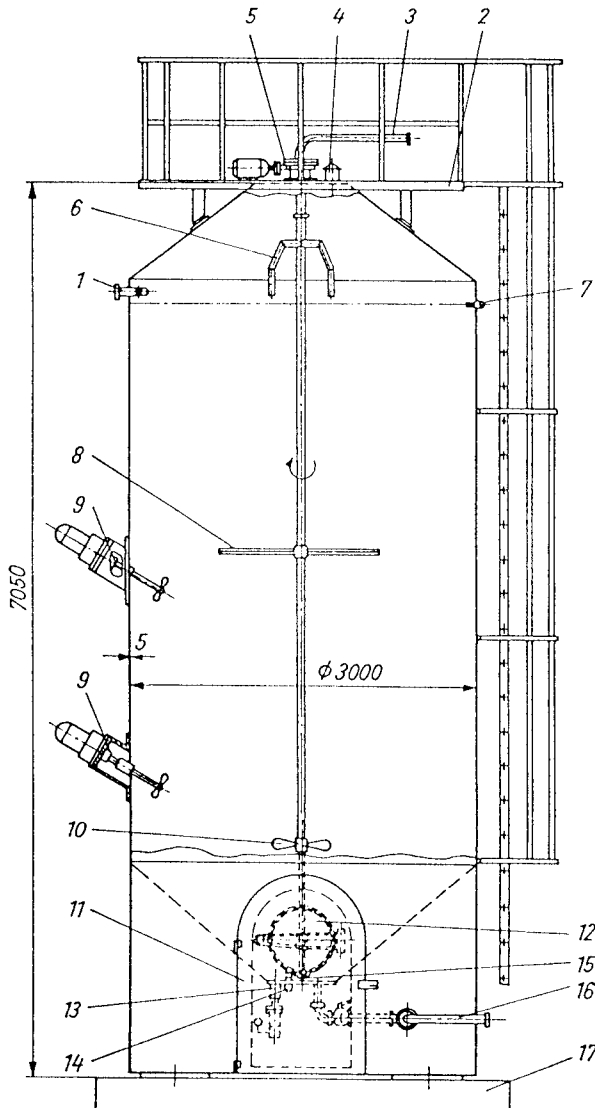


Figure 4./1 Silo. Net volume 40 m³

(1) Milk inlet (2) Silo platform with ladder (3) Inlet for cleaning fluids (4) Deaeration outlet (5) Drive for sprayball system and central stirrer (6) Sprayball system (7) Electrode for level control (8) Upper stirrers (9) Lateral stirring system (at 90°) (10) Lower stirrer wings (11) Manhole (12) Manhole lid (13) Pressure transmitter for level control (14) Level control electrode (tank empty) (15) Base bearing (for stirrer system) (16) Milk outlet; cleaning fluid outlet or circuit (17) Foundation

The level of foreign material is constantly reduced by an improved hygiene during milking; however, a clarification process in the dairy is absolutely necessary, and is even required by law. During clarification dirt particles as well as protein particles including enclosed microorganisms are reduced and the bacterial level is slightly reduced.

- Clarification does not replace effective bacterial inactivation. Inactivation must follow the clarification step.

4.2.2.2. Process

A preclarification is done by the sieves situated above the weighing balance or by the tubular sieves (Figure 4./2) in the inlet pipe into the processing section. This permits the removal of coarser particles only.

A more intensive clarification can be achieved by three operations:

- a) Filtration
- b) Use of cyclones
- c) Separation

These processes are different in efficiency, principle and design of the equipment and are used alternatively.

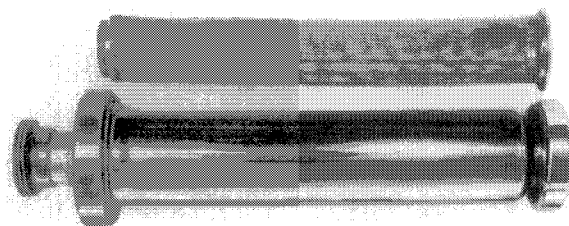


Figure 4./2
Tubular sieve in operation

The efficiency or the achieved clarification effect can be checked by a simple filtration method. One liter of milk passes through a simple cloth or cotton wool filter, and the residual dirt particles are retained on the filter surface. After drying of the filter, the sample is evaluated. Compared with a reference sample, we have four classes: A, max. 7.5 mg/l; B, max. 15 mg/l; C, max. 22.5 mg/l and D, max. 32.5 mg/l. For example, class B has a dirt particle load of at most 0.0015% of the milk volume.

Filter. In order to achieve the desired filtration effect, the filter material must have pores of 25–100 μm . The smaller the pores, the greater the separation effect and the shorter the filtration times. For a filtration installation with a flow of 10,000 l/h we can assume the following times:

Pore size	45 μm	1–2 hours
Pore size	100 μm	up to 10 hours; a filter change after 6 hours is recommended

The filters in Figure 4./3 consist of a stainless steel body wherein a filter with a small-pore nylon cloth is placed, which has been closed with a tight-fitting lid. Milk passes from top to bottom. After 3–4 hours of operation, the filter bag must be cleaned. For a continuous process, a double filter must be installed so that during the cleaning of one filter, the other filter can be used. The flow for such a filter can be up to 15,000 l/h.

The advantages of filtration systems are simple construction and low energy requirement. Disadvantages are low efficiency and the fact, that the milk, which is to be cleaned, must pass through a constantly developing dirt layer. As this residual layer can remain in the filter for several hours, the bacterial load of the milk will increase.

Cyclones. In Europe, cyclones are rarely used for milk clarification. The clarification effect is similar to that of filters with a pore size of $> 100 \mu\text{m}$. This results in only a coarse cleaning of milk. The principle is similar to that shown in Figure 10./1 and the apparatus described there.

Separator/Centrifuges. Centrifuges have the highest separation effect, and particles with a diameter of 4–5 μm are affected. The clarification efficiency depends on the type of centrifuge. Here we distinguish between de creaming centrifuges, clarification centrifuges and bacterial centrifuges.

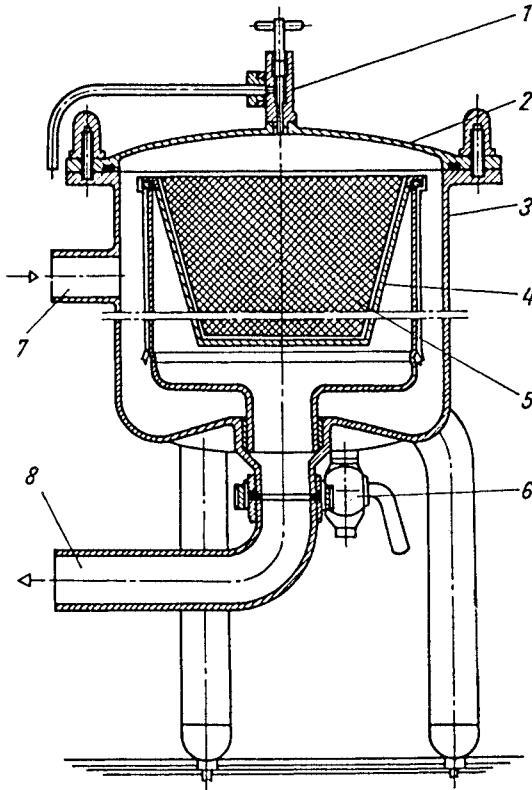


Figure 4./3 Milk filter

(1) Deaeration valve (2) Cover (3) Filter container (4) Filter insert (5) Nylon bag (6) Discharge valve (7) Milk inlet (8) Milk outlet

When both clarification and separation of milk must be done, which is the normal case in a dairy, de creaming centrifuges are used. This means that both activities, clarification and de creaming, are combined in one operation with a three-phase separation (dirt, skim milk and cream). The resulting compromises in the design of the centrifuge lead to a less intensive clarification effect than in specialized clarification centrifuge.

The clarification process proper takes place in the rotating bowls. In a clarification separator the ratio of bowl diameter to disk diameter is greater than in the de creaming bowls, resulting in a larger sludge container. In most cases the 10–20 disks have no holes (Figure 4./4), and on the surface are 6–12 baffles with a thickness of 1–3 mm which are evenly spaced. These baffles control the disk distance and influence the flow patterns. In disks with holes, the baffles are situated on the periphery of the disks in order to obtain a longer separation distance.

In later and above all high-capacity designs, the bowls are equipped with nozzles, so that the sludge can be removed periodically during the clarification process, without interrupting the operation and dismantling the centrifuge. With this so-called partial desludging, about 0.05–0.1% of raw milk is discharged, which results in a discharged liquid milk sludge and not a solid sludge.

Working principle of the clarification bowl (Figure 4./5). Raw milk is pumped through the central pipe to the rotating bowls by way of the distributor (9) and passes through the

slit openings into the sludge area (7). The dirt separation takes place in the disk assembly (4), where milk is enclosed by two adjacent baffles between two disks. One baffle leads to the rotation, whereas the other baffle leads the flow to the center. The dirt particles which have a higher specific gravity, are separated by the centrifugal forces from the milk and settle on the inner surface of the bottom part of the disk. The clarified milk rises on the outer surface of the distributor (9) and reaches the baffle (2). The fixed installed baffles lead the milk to the outside with a pressure of about 5.4 bar. Volume flows V of 10–30 m^3/h can be obtained with bowl rpm values of 5–6000 per min. Bacterial centrifuges (bactofuges) are described in Section 4.2.6.

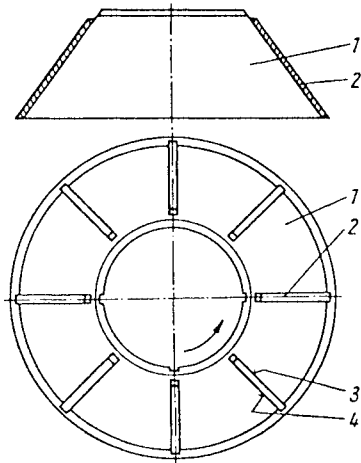


Figure 4/4 Bowl of a milk cleaning separator

(1) Bowl (2) Baffle (3) Guiding side (4) Directing side

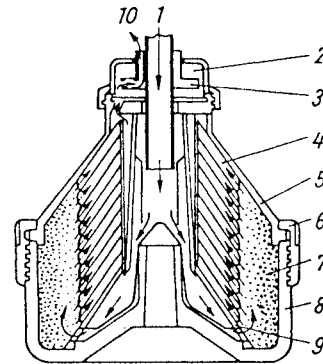


Figure 4/5 Bowl of a clarification separator

(1) Milk inlet by central pipe (2) Paring chamber (3) Grip (4) Bowl assembly (5) Bowl cover (6) Closing ring (7) Sludge area (8) Bowl bottom part (9) Distributor (10) Outlet for clarified milk

4.2.2.3. Centrifuge sludge

The centrifuge sludge (obtained during clarification) is solid and consists of dirt particles, blood particles and other foreign matter, especially milk protein. In addition, there is a very high load of microorganisms, and pathogens cannot be excluded.

This sludge is fairly solid with non-self-cleaning separators (clarification separators are part of this group of equipment) and has a dry matter content of about 35%. In self-cleaning separators, this sludge is in the form of a liquid (milk with a high dirt and bacterial load).

- If clarification residues with their high nutrient content are to be used in animal feeding, an infection risk must be excluded.

The liquid residues whose composition is shown in Table 4./1, can be sterilized in a simple way by either steam sterilization or an alkali treatment. Solid sludge residues are more difficult to clean. This sludge must be burned or disposed of by sending it to animal disposal plants.

4.2.3. Decreaming

4.2.3.1. Terms and definitions

During processing, milk fat is removed partially or completely in order to:

- a) Obtain a fat-reduced or fat-free milk
- b) Concentrate milk fat for the production of high-fat products
- c) Standardize the fat content of milk

Table 4./1 Composition of milk sludge

Substance	level in %
Total dry matter	14–18
Protein	6–8
Fat	0.25–0.35
Lactose	ca. 4.7
Nonlactose substances	1.5–3

- Decreaming (separation, centrifugation) is the mechanical separation of milk into cream and skim milk by means of centrifugal forces.

The decreaming process has significant economic importance, as it controls the efficiency of the fat separation. The key objective is to manufacture a skim milk with the lowest possible fat content, which corresponds to good decreaming efficiency. Knowledge of the basics of the fat separation is important for an optimal decreaming process.

4.2.3.2. Decreaming process

Decreaming is based on the facts that fat exists in polydisperse system in an emulsified state and that the specific density difference between milkfat ($\rho = 0.93 \text{ g/cm}^3$) and skim milk ($\rho = 1.035 \text{ g/cm}^3$) is fairly large. Basically two processes for fat separation are possible, natural decreaming and separation with machines. Natural creaming has no industrial significance and will not be discussed here.

Decreaming with machines. When a centrifuge bowl, filled with liquid, is put into rotation, the liquid surface level is lowered at first, and a rotation paraboloid is created (Figure 4./6a). With an additional increase in revolutions, the surface level is lowered to the rotation axis and then rises in parallel. At corresponding high revolutions in the bowl a liquid ring is created (Figure 4./6b)

Imagine particles of skim milk and fat with the same particle diameter in a rotating liquid (4./7), the resulting force acts toward the inside. It corresponds to the force, according to motion theory, which is required to accelerate a body moving in a circle and maintain it in an orbit. This force is called the centripetal force F_{cp} ; it is opposed to the centrifugal force F_{cf} .

In this example, the skim milk particles enter a phase in which the forces are in balance, as $F_{cp} = F_{cf}$ (Figure 4./7a). Because of their lower specific density less centrifugal force is exerted on fat particles of equal size, resulting in $F_{cp} > F_{cf}$ (Figure 4./7b). The difference in force here is very small, so the fat particles migrate slowly toward the inside. The Stokes' formula can be applied for the separation velocity v_s :

$$v_S = \frac{8}{9} \cdot \Pi \cdot r^2 \cdot \frac{\rho_{SM} - \rho_F}{\eta_{SM}} \cdot n^2 \cdot R$$

v_S	separation velocity	η_{SM}	viscosity of skim milk
r	radius of the fat particle	n	bowl revolutions
ρ_{SM}	specific gravity of skim milk	R	distance of fat particle from the bowl axis
ρ_F	specific gravity of fat		

We can deduce from this equation, that the size of the particle has an exponential effect on the separation velocity. The velocity is also controlled by the difference in specific density of the dispersed particles $\rho_{SM} - \rho_F$ or the quotient $(\rho_{SM} - \rho_F)/\eta_{SM}$ as a characteristic of the substance.

In order to shorten the distance for the fat particles and thus accelerate the de creaming, disks are inserted into the bowl which form a multitude of thin milk layers with the corresponding short distances. At the same time the fluid pressure is reduced.

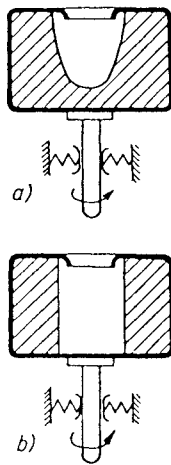


Figure 4.6 Characteristics of a liquid in a rotating bowl

a) Low revolutions b) High revolutions

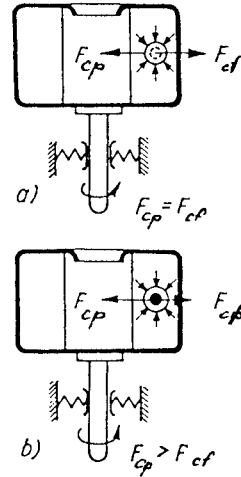


Figure 4.7 Performance of particles of different specific gravity in a rotating bowl

a) Skim milk particle b) Fat particle F_{cp} resultant of the fluid pressure (centripetal force) and F_{cf} (centrifugal force)

Cream yield and fat content. Depending on the cream fat content, about 8–15% of the milk volume are converted into cream. The cream yield (CY) can be calculated approximately as follows:

$$CY = \frac{f_{FCM} - f_{SM}}{f_C} \cdot 100\%$$

The cream fat content can be varied by modifying the cream discharge volume of the separator. The flow can be controlled by a reducing valve and is then read by a flowmeter. The setting of the flow for cream is calculated as follows:

$$V_C = \frac{V_S \cdot (f_{FCM} - f_{SM})}{f_C - f_{SM}}$$

The relationship of the cream fat content to the position of the cream flow indicator is given in Figure 4./8. The relationship between milk (to be skimmed and its fat content) and the volume flows (for cream and skim milk) with their corresponding fat contents are as follows:

$$m_{FCM} = m_C + m_{SM}$$

$$\frac{m_C}{m_{SM}} = \frac{f_{FCM} - f_{SM}}{f_C - f_{SM}}$$

$$DM_C = \frac{DM_{SM} (100\% - f_C)}{100\%} = \frac{DM_{FCM} (100\% - f_C)}{100\% f_{FCM}} = \frac{W_C}{10}$$

$$f_C = \frac{f_{FCM} \times (f_{FCM} - f_{SM})}{m_C} + f_{SM}; f_C = 100 - 1.1 \times W_C$$

where:

V_C	volume flow of cream in l/h	V_S	flow of the separator in l/h
m_{FCM}	mass of full cream milk in kg	m_C	mass of cream in kg
m_{SM}	mass of skim milk in kg	CY	cream yield
DM_C	dry matter of cream in %	DM_{SM}	dry matter of skim milk in %
W_C	water content in cream in %	f_{FCM}	fat content of full cream milk in %
f_{SM}	fat content of skim milk in %	f_C	fat content of cream in %

4.2.3.3. Factors influencing decreaming precision and quality

- Decreaming precision is expressed by the residual fat content in skim milk in %. Limits are in the range 0.01–0.04. Fat levels of > 0.04 % indicate decreaming deficiencies.
- The decreaming quality is the result of the decreaming process considering all factors and is shown in absolute fat losses.

Pretreatment of milk. Strong mechanical influences on milk during pretreatment, especially shear forces, have negative effects on the decreaming quality. These influences can be:

- Heavy shaking during transport with insufficiently filled chambers
- Multiple pumping, especially of chilled milk
- Incorporation of air, e.g., due to leaks in the milking installations, during pumping or during filling of the storage containers
- Too intensive stirring during farm chilling or storage

- e) Multiple separation and reblending of cream into skim milk, which can reduce the decreaming precision by a factor of 6

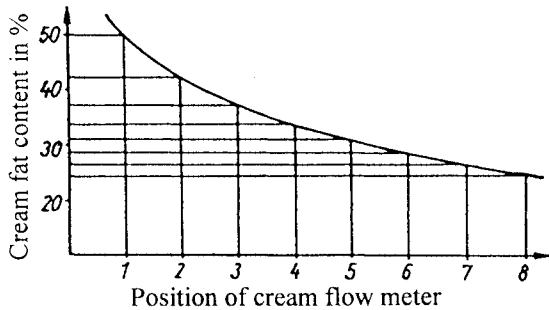


Table 4./8 Cream fat content as a function of position of cream flow indicator for the separator type MZA 10

These influences reduce the size of the fat particles to such a level that they become too small for separation. At the same time, the fat globules can be destroyed, creating free fat which cannot be separated and migrates into the skim milk. Furthermore, lipolytic reactions are enhanced.

- Milk must be treated extremely carefully before decreaming.

Decreaming temperature. Temperature has an effect on the decreaming precision because of its effect on viscosity. With increasing temperature the viscosity decreases and reaches a minimum at 75–85 °C. Above this range, heat denaturation of the serum proteins begins and raises the viscosity again. The decreaming precision is reduced, and the sludge levels in the separator increases.

Cold decreaming of milk at reception temperatures of 5–10 °C permits an energy saving; however, the separator flow rates must be reduced by 30–50% in order to achieve the same decreaming precision.

- The optimum decreaming temperature is 50–60 °C; these are also the design parameters for heat exchangers in dairy processing lines.

Fat content of milk. The natural fat content of milk has no influence on the decreaming quality. This is controlled only by the natural size of the fat globules. The larger the fat globules or aggregates, the better the decreaming quality. When separating milk with a higher fat content (fat-enriched), performance deterioration cannot be observed; however, the fat content of the skim milk is slightly higher. The nonseparated fat is in a smaller volume than in milk with a lower fat content; therefore a reduction of the fat losses is observed.

Influences of the separator. The construction and principles of the separator have a major influence on the decreaming quality. Sophisticated separators can achieve a decreaming precision of 0.005%. Low performance of the separator can be due to:

- Revolutions too low due to insufficient drive or defective assembly of the separator
- Unstable bowl due to defective bearing, wrong assembly or imprecise (nonhorizontal) installation of the bowl
- Flow rates too high
- Defective gaskets in the cream section
- Defective cream disk

- f) Incorporation of air due to low flow rates
- g) Cream fat content set too high

4.2.3.4. Separators

Separators in the dairy technology, also called centrifuges, can be classified according to their design and construction.

Here we distinguish between four types of separators:

- a) Decreaming separators (concentrators). This type is widely used, as clarification and decreaming are combined. It can be equipped with devices for fat standardization, in which case it is called universal separators.
- b) Milk clarification separators (clarifiers). This serves only for clarification of milk.
- c) Homogenization centrifuges (clarifixators). This disintegrates the fat globules (4.2.4).
- d) Bactofuges. This type provides mechanical reduction of the bacterial load.

Design. Open separators. These are characterized by an open top milk inlet and an open, i.e., pressureless, skim milk and cream outlet.

Semiclosed separators. Here we have an open-top milk inlet with a hollow spindle under atmospheric pressure. The skim milk and cream are discharged into closed pipes and at elevated pressures. The solid discharge is done manually, after stopping and dismantling the separator. This design is also called a non-self-cleaning separator.

Closed or hermetic separators. The milk is transferred in a closed pipeline under pressure, which is mostly flow controlled. The product outlet is identical to the semiclosed separators. This design is normally used for selfcleaning (self-desludging) separator; i.e., the dirt is discharged periodically without interruption of the process. With closed separators incorporation of air is nearly totally excluded, which results in the following advantages:

- a) Gentle treatment of the milk in the bowl, as its volume is taken up entirely by the liquid
- b) Higher decreaming precision, up to 0.005%
- c) Lower risk of burning and therefore lower residues in the heat treatment installations

With non-self-cleaning separators, the operational time of the process line is governed by the volume of the sludge container of the separator; with self-cleaning separators, it is governed by the residual deposits of the heat treatment installations.

4.2.3.4.1. Semi-closed separators

The construction of this type is shown in Figure 4./9 and is described in Overview 4./2. The separation process proper takes place in the bowl. Exact knowledge of its design and function is important, as improper assembly and maintenance can lead to significant operational disruptions.

Working principle of the separator bowl (Figure 4./10). Whole milk is transferred via the central pipe (8) to the distributor (2) and is then put into rotation. In the distributor, which also serves as the base for assembly of 110–130 disks (3), coarse dirt particles settle down in the conical bottom part. The milk flows over openings, which are inclined toward the

rotational axis, into the disk assembly. Here it rises in channels, which are parallel to the rotational axis; the channels are formed by the rising holes of the disks and the milk is distributed in thin layers in the space between the disks, (distance of 0.5–1.0 mm). Here the real separation of milk into cream and skim milk takes place, as well as the centrifugation of dirt. The dirt is collected in the sediment chamber in the bottom part of the bowl (1).

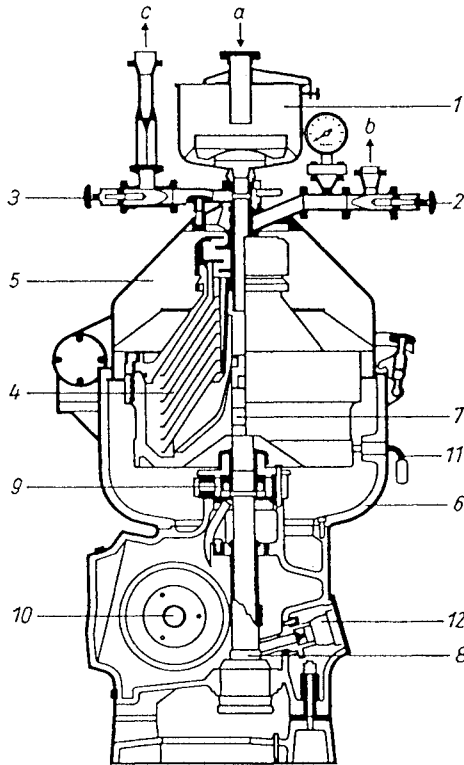


Figure 4./9 Cross section of a de creaming centrifuge, type MZA 10, capacity 10.000 l/h

a) Full cream milk inlet b) Skim milk outlet c) Cream outlet

(1) Inlet vessel (2) Skim milk screw with pressure gauge (3) Cream screw with cream flowmeter (4) Bowl with disk assembly (5) Cover (6) Frame (7) Bowl spindle (8) Shaft bearing (9) Top bearing (10) Bowl spindle (11) Bowl arresting screw (12) Revolution indicator

The major part of the liquid (skim milk) moves toward the outside, and the cream (which is lighter) moves in the opposite direction toward the center. In a slit between the bowl base (2) and the disk inner rim, the cream rises to the cream retention chamber and goes into the cream outlet.

After passing the disk space, the skim milk goes into the bottom part of the bowl and flows as a liquid ring into the slit between the bowl cover and the separation disks into the skim milk chamber. The separation disks serve to keep the skim milk separate from the cream. The skim milk is then directed via the disk of the skim milk chamber into the skim milk outlet. The fixed separation disks have the effect of a rotating centrifugal pump, so that in each chamber the required pressure (for transporting the liquid) is generated.

4.2.3.4.2. Closed separators

The design of these separators is basically the same as that shown in Overview 4./2. The key difference is in the closed milk inlet into the bowl, either from the top with an inlet pipe or from the bottom with a hollow spindle.

The separator shown in Figure 4./12 is also equipped with a self-cleaning bowl. The dirt (which is separated from the milk) is collected in a bowl (which is conical to the outside) and is ejected periodically through ports. This permits the separator to be included

in a CIP circuit without requiring time for disassembly. The operating time is independent of the sludge container capacity which permits a multishift continuous operation.

Overview 4./2 Cutaway of a decreaming separator (see Figure 4./9)

Part	Function	Remarks
Inlet container (1)	Ingress of milk	An inserted impact sheet gives an even milk distribution, minimizing the incorporation of air into the drum. The inlet container can be replaced with a pipe having a show glass.
Skim milk screw (2)	Control of skim milk flow rates	The counterpressure in the drum creates a constant liquid level. Operating pressure is 5.0-5.5 bar
Cream screw (3)	Control of cream flow rates	The lower the flow rate, the higher the fat content of the cream.
Drum (4)	Decreaming and cleaning	Rotates at 6-7000 rpm.
Cover (5)	Contact protection over rotating drum	Steel cover to be opened sideways
Frame (6)	Houses gear drive and drum	Of cast iron, coated with stainless steel. An exact horizontal position is the basis for smooth operation of the drum.
Drum spindle (7)	Transmission of driving forces to the drum	The spindle is inserted into the bottom part of the drum.
Base bearing (8)	Supports the spindle	
Top bearing (9)	Supports the spindle	The top bearing is inserted onto a spring seating in order to absorb vibrations of the bowl.
Gear drive (10)	Transmission	The gear drive is mounted on rubber shock absorbers and transmits the horizontal rotation of the drive into a vertical rotation of the spindle. It is firmly attached with a centrifugal clutch.
Clutch	Connection between motor and drive shaft	Made as centrifugal clutch or hydraulic clutch, transmits only limited circular forces, yielding a drive-saving slow startup of the drum after the start of the motor; reaches operating speed after 8-10 min.
Arresting screw (11)	Fixes the drum after shutdown; for disassembly	The bowl cover ring can be opened easily for disassembly and cleaning and is tightened after reassembly. Loosen the arresting screw before startup!
Tachometer (12)	Indication of RPM	
Brake	Reduces shutdown time	Is pressed uniformly against the drum clutch by a spring, in some other types against the bowl body.

Such a separator has additional support systems (see overview 4./2) such as hydraulic valve control system, controls for valves and motors and a sludge sterilization installation.

Working principle of the separator bowl (see Figure 4./13). The milk flow is the same as in a non-self-cleaning bowl. The sludge (which is ejected during the decreaming) is accumulated in the sludge chamber (formed in the shape of a double cone). The floor of the double cone can be moved hydraulically to a lower position, and the sludge leaves the bowl through the annular slit while rotating at operating speed. The ejected liquid goes via the sludge receptacle into the sterilizing container.

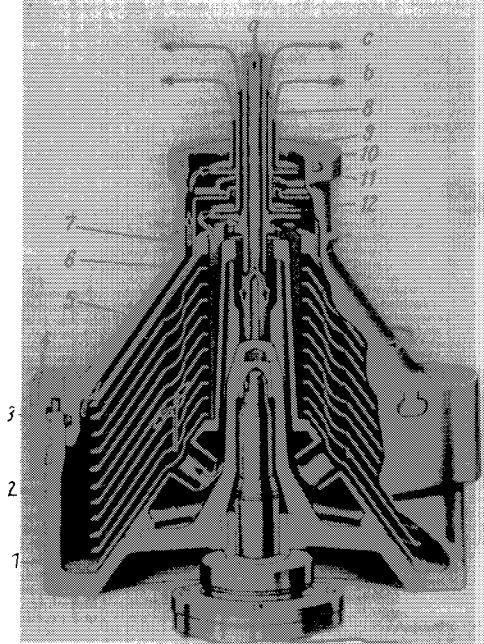


Figure 4./10 Design of a separator bowl

a) Whole milk inlet b) Skim milk outlet c) Cream outlet

(1) Bottom part (2) Distributor or disk tripod (3) Disk assembly (4) Bowl cover ring (5) Bowl cover (6) Separation disk (7) Upper disk (8) Inlet or center pipe (9) Skim milk chamber lid (10) Skim milk chamber closure ring (11) Skim milk paring disk (12) Cream paring disk

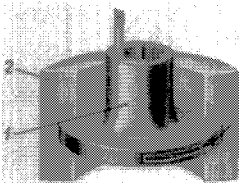


Figure 4./11 Disk separator, surrounded by liquid

(1) Separator disk (2) Liquid level

Closing process. The bowl can be closed when the operating speed reaches 4800 rpm. The piston (17) is first in the lower position (left side of Figure 4./12). The control water valve system sprays water from an inlet (14) into the lower chamber (16) of the bowl bottom part (8) and then reaches the closing water chamber (9) via a hole (16). Due to the centrifugal acceleration of the bowl, the control liquid reaches such a high pressure that the piston is pushed tightly against the bowl cover gasket. The bowl is thus closed, and the separation can take place. The closing force here is greater than the forces (from the top) from the filled bowl.

Opening process. To open the bowl during operation, water is transferred into a second shower through a slit and is sprayed into the top control water reservoir (13). The opening water then passes through connection holes into two bowl valves. Such a high liquid pressure is created by the high centrifugal forces in these linked chambers that the closing device of the closing water reservoir is lifted, and the closing water of the reservoir (9) can be drained. The outflowing closing water has a higher pressure than the bowl inner pressure and influences the piston so that it moves to the bottom. The opening outlet of the bowl bottom part is released, and thus activates the desludging. After the desludging, the closing process is reactivated.

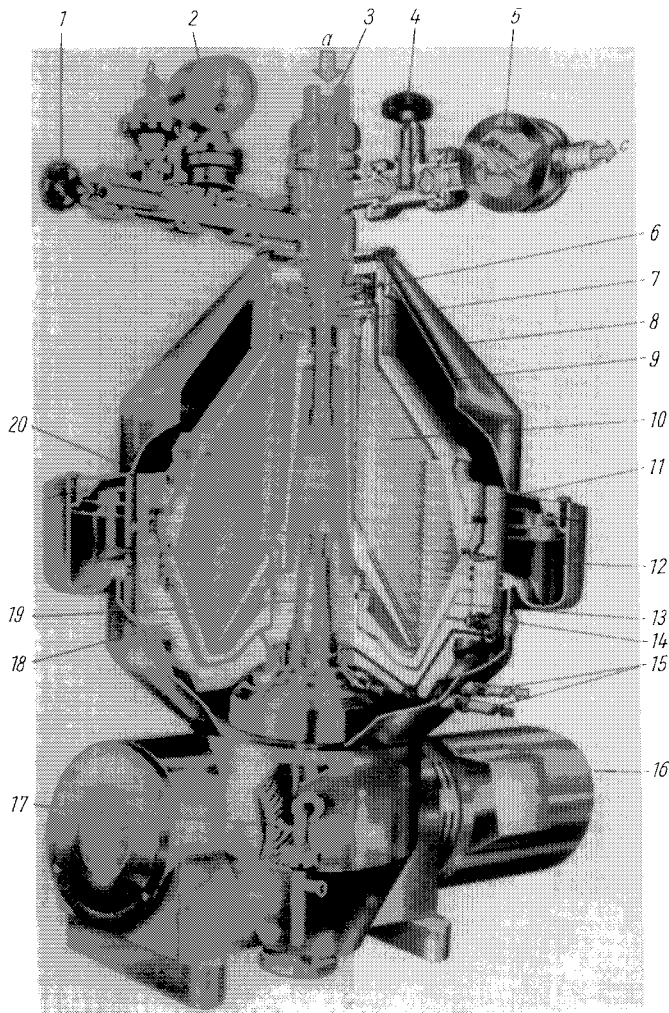


Figure 4./12 Self-cleaning separator, type SMZA, capacity 20,000 l/h

a) Raw milk inlet b) Skim milk outlet c) Cream outlet

(1) Skim milk screw (2) Gauge for skim milk pressure (3) Inlet tube (4) Cream screw (5) Flowmeter for cream (6) Skim milk paring disk (7) Cream paring disk (8) Lid (9) Bowl cover (10) Disk stack (11) Bowl closing ring (12) Sediment chamber (13) Piston lever (14) Control water discharge (15) Control water inlet (16) Drive (17) Gear wheel (18) Bowl bottom part (19) Shaft (20) Distributor

Program control device of a separator. The control device in Figure 4./14 is for the separator (Figure 4./13). Control of the separator and the desludging process can be done in a manual or automatic mode. The following control activities must be executed:

- a) Control of motor startup and thermal control of the motor
- b) Switching of the controls from “startup” to “operation” once the set rpm of the bowl has been reached
- c) Closing of the bowl after starting the automatic program and activation of the de-

sludging program in preselected uniform intervals and a preselected program, with the following choices:

1. Partial desludging
2. Complete desludging
3. Special program with alternating partial and complete desludging
4. Complete or partial desludging at any time
5. Automatic complete desludging

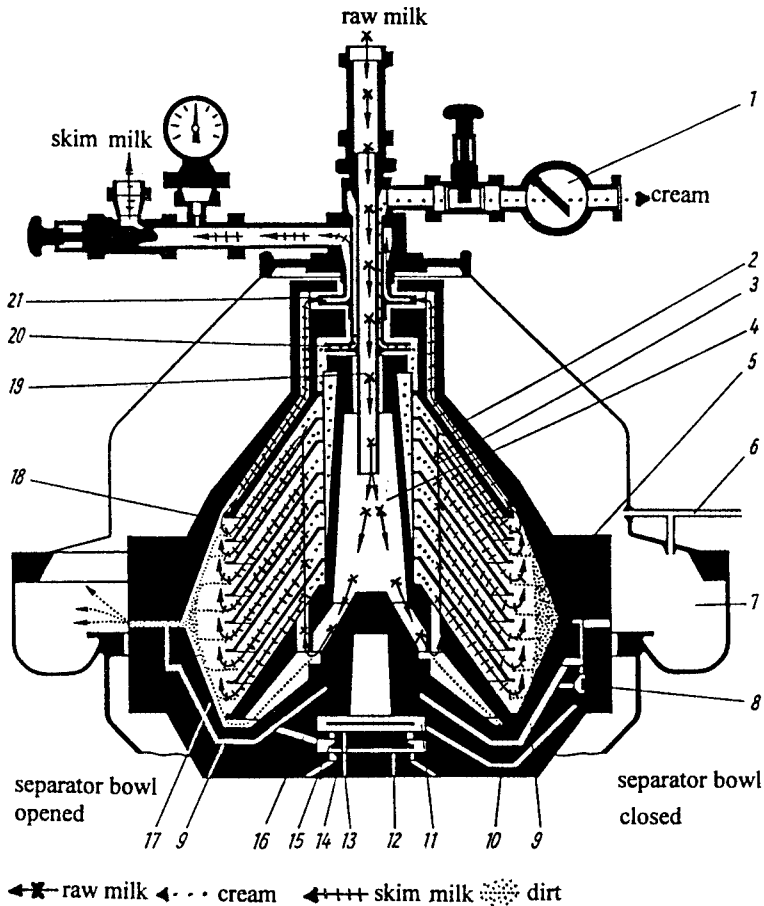


Figure 4./13 Cutaway of a self-cleaning separator bowl, type SMZA

(1) Flowmeter for cream (2) Separation disk (3) Liquid rising channel (4) Distributor (5) Sludge chamber (6) Rinsing device (7) Sludge receptacle (8) Bowl bottom part (9) Closing water chamber (10) Connecting drillhole (11) Upper control water chamber (12) Drillhole to lower control water chamber (13) Drillhole to upper control water chamber (14) Control water inlet (15) Lower control water chamber (16) Connecting drillhole (17) Piston (18) Bowl lid (19) Inlet tube (20) Cream paring disk (21) Skim milk paring disk

Complete desludging can be done only by interrupting the milk supply and displacing the milk from the bowl; otherwise the milk losses would be too high. Partial desludging can be done with a closed or open milk inlet.

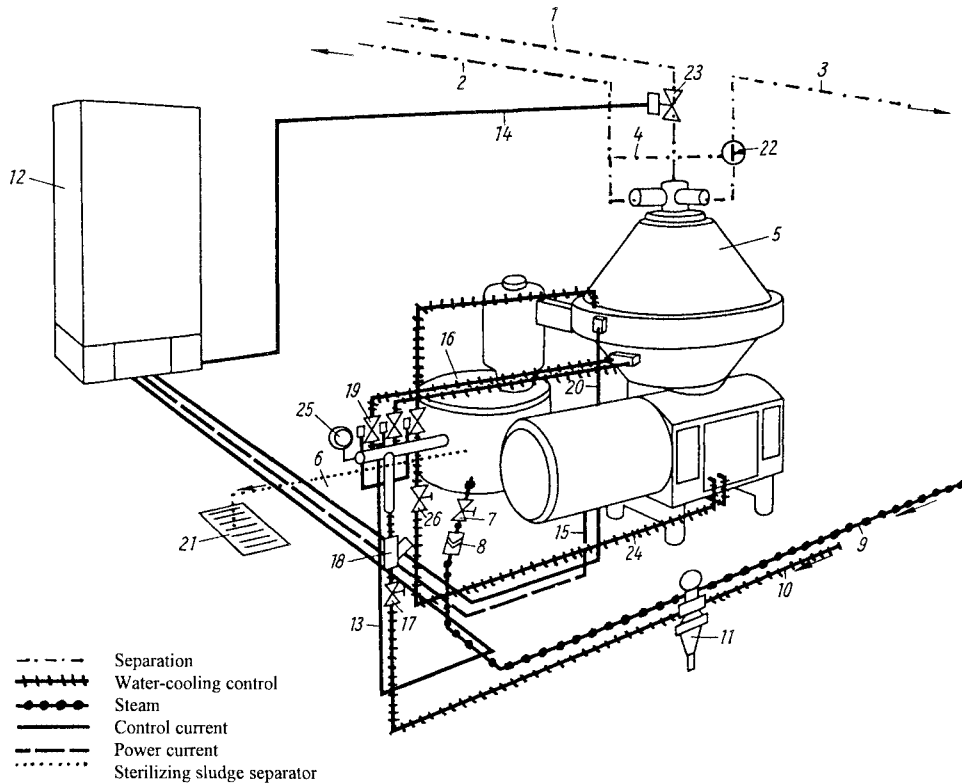


Figure 4./14 Product and control pipelines for self-cleaning separator, type SMZA

(1) Raw milk feed pipeline (2) Skim milk discharge pipeline (3) Cream discharge pipeline (4) Connecting pipeline between skim milk and cream discharge pipelines (5) Separator (6) Discharge for sterilized milk sludge (7) Steam shutoff valve (8) Steam check valve (9) Steam pipeline to steam distributor (10) Control water feed pipeline (11) Pressure reducing valve (12) Control panel (13) Control pipeline to magnetic valves (14) Control pipeline to infeed shutoff valve (15) Electric cable (16) Sterilization chamber (17) Control water shutoff valve (18) Control water filter (19) Control water valve system (can be operated manually) (20) Electrical cable to arresting position (21) Drainage (22) Three-way valve (23) Infeed shutoff valve (24) Chilled water line to oil cooler (25) Pressure gauge (26) Shutoff valve for gear lubricant refrigeration

4.2.4. Homogenization of milk

4.2.4.1. Basics

- Homogenization is the disintegration of particles in which uniformly or non-uniformly distributed phases of a liquid reach a higher level of mixing and the distribution level stabilizes.

The main purpose of homogenization in the dairy industry is to reduce the size of the fat globules and achieve a uniform diameter of 0.5–1 μm (Figure 4./15). This results in both desirable and undesirable changes. Advantages are:

- a) Increase of the total surface of the fat globule, which prevents or delays creaming of the fat and increases light reflection
- b) Enhancement of taste and texture
- c) Increase in digestibility

Disadvantages are:

- a) Increased area for attack of microbial lipase, resulting in lipolytic changes
- b) Increased sensitivity to light influences, leading to taste defects such as “rancid,” “soapy” or “oxidized”
- c) Increased area for microbial contamination
- d) Reduced thermal stability of the protein (homogenization must be done after the UHT treatment for UHT milk)

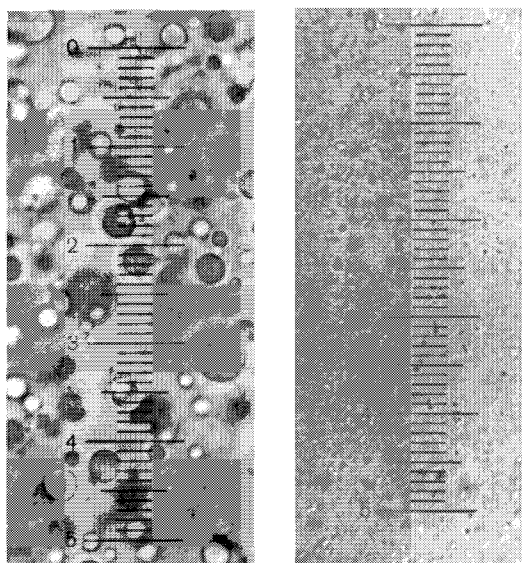


Figure 4/15
Microscopic image of fat globules in whole milk
 a) Nonhomogenized
 b) Homogenized
 One notch = 1 μ m

In addition a small viscosity increase is observed, which can be advantageous in some cases. For certain products, homogenization has the following purposes:

- a) Fresh milk—creaming of fat is avoided, and a taste improvement is achieved.
- b) Coffee cream, evaporated milk—avoids creaming, improves the “whitening” power in coffee.
- c) Cheese milk—reduces the fat content of the whey, provides a more uniform fat distribution in the cheese mass, inhibits “fat sweating” of cheese and enhances the biochemical fat degradation (e.g., with special fungus cheese).
- d) Acidified dairy products—improvement in consistency and taste, more stable acid gel and reduced whey syneresis in yogurts and other coagulated products.
- e) Milk mix beverages—good distribution of additives and fat.
- f) Ice-cream mix—reduced buttering of fat during freezing.

The reduction of the diameter of the fat globules results in an increase of the total surface of the fat globules, as the surface S is inversely related to the diameter d .

$$\frac{S_1}{S_2} = \frac{d_2}{d_1}$$

As the number of fat globules is increased by a factor of 1000, an 8 to 10- fold increase in surface occurs. This surface increase prevents creaming, as the buoyancy and the gravity neutralize each other. The membranes of the fat globules disintegrate during homogenization. The rapidity of the process and the high surface tensions between the particles and the aqueous phase result in the creation of new membranes around the smaller fat globules, thus preventing the release of free fat into the aqueous phase. However, the temperature must be $> 30\text{ }^{\circ}\text{C}$, so that the fat remains liquid and does not exist in a crystalline fraction.

The original membrane substance is insufficient to create a new membrane substance. The result is that casein micelles and serum proteins are incorporated into the newly created membranes, and the typical euglobulin is reduced. As the euglobulin plays a significant role in the cream process, creaming of the fat is therefore reduced too. Deformation of the casein micelle during homogenization has another effect: during the production of casein, a softer coagulate is developed. This phenomenon must be considered during cheese manufacture and has (for acidified products) a favorable influence on digestion in the stomach. During the membrane development, a casein micelle and two fat globules can attach to each other and, under certain conditions, defined agglomeration and creaming can occur. This newly created fat layer is significantly different from the fat layer of normal natural creaming. It contains more proteins, is softer, and can be easily redistributed in milk by shaking or stirring. This phenomenon is used for a partial homogenization of fresh milk (see 4.2.4.2).

The targeted fat globule diameter during homogenization depends on the foreseen utilization of the milk. For fresh milk, diameters of $1.0\text{--}1.5\text{ }\mu\text{m}$ are sufficient to avoid creaming for a few days. For UHT milk and other long-shelf-life products, diameters of $0.2\text{--}0.7\text{ }\mu\text{m}$ should be targeted, which totally eliminates agglomeration and creaming.

The homogenization effect (or homogenization degree) indicates the extent to which the creaming of fat is avoided. As an example of its determination, 250 ml of milk are measured in a cylinder and is stored for 48 h in a refrigerator. The fat content is determined from the upper 1/10 (sample a) of the sample as well as from the lower 9/10 (sample b), and the homogenization effect is then calculated as follows:

$$HE = \frac{a - b}{a} \cdot 100\%$$

For fresh milk, $H > 60\%$, for UHT milk $H > 80\%$ and for yogurt milk $H = 80\text{--}90\%$.

4.2.4.2. Processes

Here we distinguish between

- a) Complete homogenization—all the milk, standardized to a defined fat content, passes through a homogenizer.
- b) Cream homogenization—only the separated cream is homogenized and is later added back to the milk.
- c) Partial homogenization—cream is blended with a certain amount of skim milk, resulting in a fat content of 13–20%. This partial flow (equivalent to 20–27% of the total milk quantity) is homogenized in a single stage at 150 bar or in a double stage

(150 bar and 30 bar) at temperatures of 50–70 °C and then added back to the main stream.

The homogenization effect is achieved by pushing liquid under a very high pressure through a very narrow orifice, whose diameter is just slightly larger than the diameter of the fat globules. In terms of the pressure we distinguish between

- a) high-pressure homogenization with $p = 100\text{--}350$ bar
- b) low-pressure homogenization with $p = 5\text{--}30$ bar

In the tight orifice very high velocities are built up resulting in high turbulence and cavitation.¹ These lead to deformation of the particles by vibration and finally disintegration. This happens either in the orifice and immediately after passing through it. Governing factors are pressure, temperature, flow and the form of orifice in the homogenizer. At first we have the following relation:

- The lower the fat content and higher the temperature and pressure, the better is the homogenization effect.

The optimal temperature range is 60–70 °C. During cream homogenization, the decreasing temperature is used, which necessitates a nearly twofold pressure increase.

The choice of suitable homogenization orifices (Figure 4./16) is of importance. When they are optimally selected, the pressure can be reduced significantly while achieving the desired effect. These relationships are important for homogenization, as the power requirements P in kW is directly proportional to the pressure p .

$$P = p \times \dot{V}$$

For complete homogenization of fresh milk at a flow rate of 12,000 l/h and a pressure p of 20 Mpa, a power P is required as follows:

$$P = 20 \cdot 10^6 \frac{\text{kg}}{\text{s}^2 \cdot \text{m}} \cdot \frac{12 \text{ m}^3}{3600 \text{ s}} = 66666 \frac{\text{kg} \cdot \text{m}^2}{\text{s}} \approx 67 \text{ kW}$$

This example shows that a pressure reduction during homogenization is advantageous and that cream homogenization is preferred due to the lower flow rates (as long as the technological conditions warrant it).

During homogenization mechanical energy is converted into thermal energy, resulting in a slight temperature increase in the product. Furthermore, bacterial colonies are inactivated; an improved inactivation effect is achieved in the ensuing pasteurization. If for technological reasons a high-temperature (ultra-high temperature, sterilization) treatment is necessary, the homogenization is done after the heat treatment, as protein stability is reduced during homogenization and a firmer fat-protein-agglomerate is created, leading to nondesirable precipitation phenomena in the product.

In the partial homogenization of fresh milk, cream is added back into milk, and the blend is heated very gently (71–72 °C), and then chilled and bottled. After a few hours, a

¹ Cavitation refers to a localized formation of gas bubbles within a material which collapse in an implosion-like manner due to rapid decompression.

minor accumulation of fat (also called cream collar) develops on the collar of the bottle. This fat accumulation—caused by the previously described agglomeration of fat globules—can be dissolved by simple shaking of the bottle, and the advantages of homogenization become evident (no fat losses on the inner bottle surface). The development of the fat collar can be used in marketing, as many consumers perceive a fat layer as an indicator of milk quality.

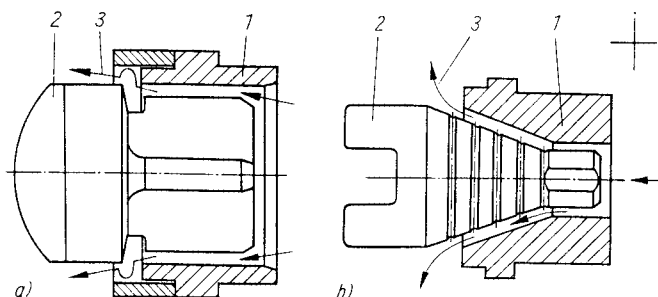


Figure 4.16 Homogenization orifices with different design. Pressure is controlled manually with a handle or lever by modifying the cone.

a) Type P b) Type C (1) Cone seat (2) Cone (3) Liquid flow

4.2.4.3. Homogenization equipment

Homogenizers (Figure 4.17) consist basically of a covered base plate, motor, triple-piston high-pressure pump and one or more homogenization stages (heads), into which the homogenization orifices are inserted. Instruments and a control system are also required.

The working principle is described here on the basis of the schematic plan in Figure 4.18. The product is pumped through a pipeline into the suction side (1) of the triple-piston pump at a pressure of 1–2 bar. During the backstroke of the piston pump (10) a vacuum is created in the cylinder, which is filled with the product. During the compression stroke of the piston the ball valve (11) of the suction side is closed, and the valve (2) of the pressure side is opened once the pressure peak has been reached. The product reaches the first homogenization stage (9), is homogenized and is pushed into the second stage (5), where an additional homogenization takes place. The pressure is set with the handle (7), by pushing a spring (6) against the cone of the orifices, thus setting the orifice distance and the operating pressure. Pressure is read on the pressure gauge (4). In case of disturbances in the pressure system, the product can be evacuated through relief valve (3) so that damages to the machine can be avoided. In single-stage homogenization of milk, a viscosity increase in milk of about 20–30% is observed, which later results in agglomeration. In contrast, in double-stage homogenization (high pressure/low pressure) the viscosity increase is < 5 % and the agglomeration tendency is low.

Other possibilities for homogenization. Clarifixator. In this machine, which works on the same principle as the separator (Figure 4.19), cream enters the chamber, the rotation of the chamber causes a fluid ring to develop around a disk with spikes. During constant immersion in the cream, these spikes break up the fat globules (mainly through cavitation). The cream is then transferred via a ring slit (4) between the inlet pipe and another central pipe into the bowl and is then blended with milk. When passing over the disk assembly in the bowl, the disintegrated fat globules are not separated and remain emulsified in the milk. The product is then discharged through the chamber. The larger fat globules

that still remain are then separated, retransferred into the chamber and disintegrated or circulate in the bowl until they cannot be separated further. The homogenization effect in the clarifixators is significantly lower than in a homogenizer; therefore this process is rarely used in milk processing.

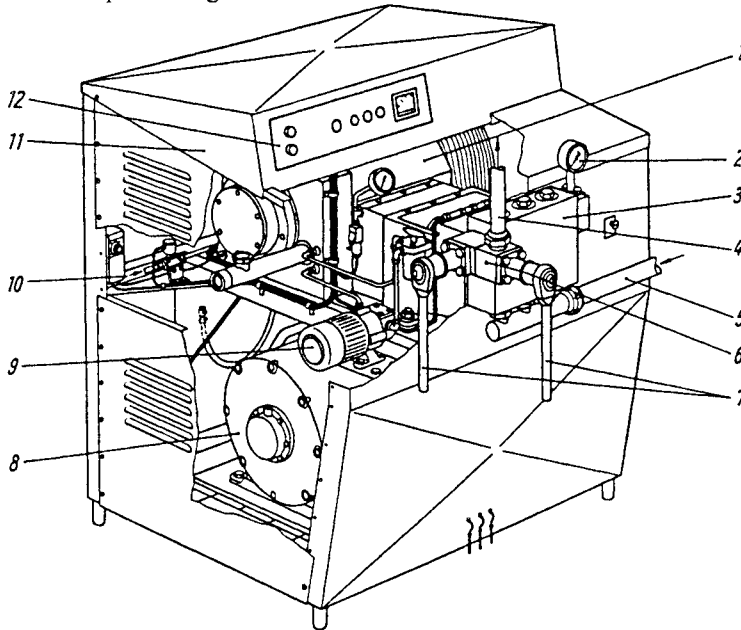


Figure 4./17 Homogenizer, type SH 30, flow rate 4–12,000 l/h; maximum pressure 350 bar, energy requirement 90 kW

(1) Gear (2) High-pressure gauge (3) Cylinder block of triple-piston high-pressure pump (4) Pressure pipe (5) Suction pipe (6) Homogenization head (double) (7) Lever for pressure setting (8) Drive motor (9) Pump for oil lubrication (10) Cooling system (11) Frame with cover (12) Electrical control system

Pumps. A similar effect is achieved in centrifugal pumps (see Section 4.4.4) due to the rotation of the impeller (rotor), which is comparable to what happens in the paring chamber of the clarifixator. The effect, however, is very small, and in general is insufficient for homogenization of milk.

Ultrasound. A membrane, vibrating in the ultrasound frequency range of 20–30 kHz, creates small voids in a liquid, which collapse after the transfer of a certain amount of energy. This disintegrates the fat globules in the same manner as during cavitation. Only a few applications are known in dairy technology.

4.2.5. Standardization of milk

Fat and protein contents are subject to significant seasonal variations, with the fat content having the widest fluctuations (see Section 2.3.1.2). The milk components (fat and protein) must be standardized in raw milk for many different applications.

Since the invention of machine-based decreaming, standardization of the fat content has been done with fairly good precision using different technical solutions. Standardization of the protein content has been made possible only in the recent past by the introduction of the membrane technique.

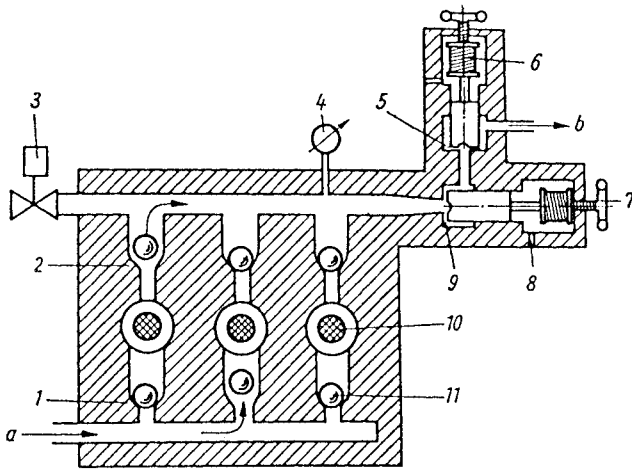


Figure 4./18
Triple-stage piston pump
with double-stage homo-
genization head

a) Product inlet b) Product outlet

(1) Suction side (2) Pressure side (3) Safety valve (4) Pressure gauge (5) Homogenization stage (6) Pressure setting spring (7) Handle for pressure setting (8) Drainage hole (9) Homogenization stage 1 (10) Piston (11) Ball valve

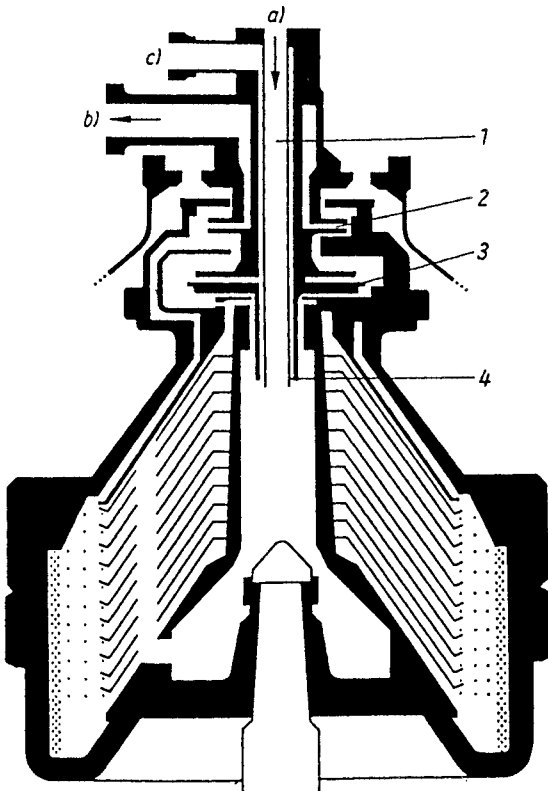


Figure 4./19 Clarifixator, type
4385 M, flow rate 5000 l/h

a) Whole milk inlet b) Whole milk outlet c) Cream outlet for reincorporating into whole milk outlet

(1) Inlet pipe (2) Paring disk for milk discharge (3) Homogenization disk (4) Annular orifice for cream return pipe

4.2.5.1. Fat standardization

Fat content is set for all fat-containing products, and the tolerances must be respected. With liquid as well as many solid products, the fat content of the milk must be adjusted (normally in treated milk).

- Fat standardization is the adjustment of a predefined fat content (in %) in milk.

For this purpose, the fat content in the raw milk must be known and needs to be determined in certain intervals or continuously. Fat standardization can be done in two ways:

- a) By blending precalculated quantities of whole milk and skim milk in silos
- b) By using standardization facilities

Blending of milk and skim milk. During the decreaming process cream is recombined with skim milk immediately after the separator. Whole milk is transferred into a silo (after it has been pasteurized and chilled) and is then blended with skim milk in such a way as to obtain the desired fat content. In a similar way, cream and skim milk can be blended in a silo in order to obtain the targeted fat content. However, a uniform fat distribution in milk cannot be obtained in this blending process due to the chilled cream (which has a high fat content), resulting in considerable fat variations. Furthermore, considerable natural creaming must be anticipated. For minor corrections of the fat content, cream with < 30% fat is used in many cases in order to have a sufficient mixing effect.

Calculation of the quantities. The quantities can be calculated with blending formulas (Pearson's square) or by calculating the fat units. As a result, we obtain blending fractions in the form of ratios or percentages or the corresponding quantities or volumes. For estimations, the following formulas can be used:

- a) setting of a target quantity with a target fat content

$$m_{V/C} = \frac{m_S \cdot f_S}{f_{V/C}}$$

- b) fat content correction by adding high-fat milk or cream

$$m_{V/R} = \frac{m_S \cdot (f_S - f_I)}{f_{V/R}}$$

- c) fat content correction by adding fat-reduced milk or skim milk

$$m_{SM} = \frac{m_I \cdot (f_I - f_S)}{f_S}$$

$m_{V/C}$	quantity of high-fat milk or cream in kg	m_{SM}	quantity of fat-reduced milk or skim milk
m_S	target quantity in kg	$f_{V/R}$	fat content of high-fat milk or cream in %
m_I	actual quantity to be corrected in kg		
f_I	actual fat content in %		

In lieu of quantity, volumes (in liters) can be used.

Standardization facilities. These facilities serve to blend liquid streams continuously. They are installed directly at the outlet of the separator and transfer only the quantity of cream into the skim milk that is required for the targeted fat content. Surplus cream is diverted.

Manually controlled installations (Figure 4./20). The principle is that after the first cream flowmeter (7) (each separator has one) a second flowmeter (8) is installed in line. The

first cream flowmeter indicates the total cream flow, whereas the second one indicates the added back quantity of cream into the skim milk. This cream quantity is controlled by a second throttling valve (5), and is read on the gauge of the cream flowmeter. With the first throttling valve (4) the cream fat content is set, and with the third throttling valve (6) the skim milk pressure (minimum 3.5 bar) is set. By changing the three-way valve (3), the transfer of skim milk can be blocked (position II), or all the cream can be added back into the skim milk (position III). With a nearly constant fat content of the milk (which is to be decreamed) as well as constant cream fat content and skim milk pressure, the fat tolerance in such a milk is $< 0.1\%$.

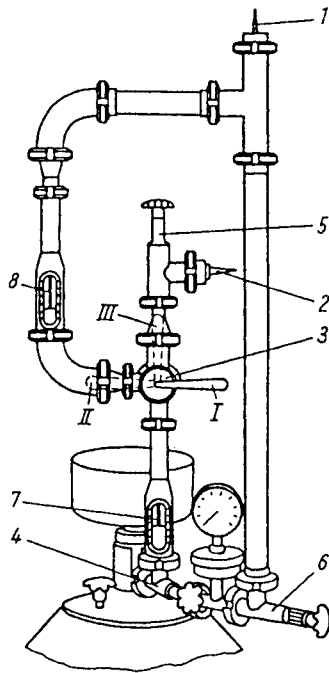


Figure 4./20 Standardization installation Type SEC

I) Standardization II) Decreaming

III) Cleaning

(1) Skim milk pipeline (2) Cream pipeline
(3) Three-way valve (4) First throttle valve
(5) Second throttle valve (6) Third throttle valve
(7) First cream flowmeter (8) Second cream flowmeter

Automatic installations. Automatic fat standardization is based on continuous fat determination. The fat content is the governing factor for the control of the flows. The fat content can be determined either by density as well as by photometric determination, and the time is < 30 s for one determination.

In the installation shown in Figure 4./21 the cream fat content is determined by using a lactodensitometer (5); the density is converted into a pneumatic signal and is used in the control unit (9). This controller actuates a valve (6) at the outlet of the separator (1) and thus modifies the cream fat content. In addition, the flow rate of the valve (10) is controlled, diverting the surplus cream once the cream flow rate has been measured by a flowmeter (7). The skim milk pressure and the flow rate are kept constant by a sensor (3) and the valve (4). Finally, the flow rate of the standardized milk is determined by a sensor (8).

4.2.5.2. Protein standardization/Membrane filtration

This standardization permits a constant protein level (which fluctuates to a certain extent) when the required filtration process is utilized. This can be advantageous in

cheese manufacturing, where fluctuations in protein level can have negative effects on the process and the finished product. A more uniform manufacturing process can be achieved by this standardization for products like yogurt, market milk and long-shelf-life products.

- The addition of this processing step is subject to the downstream utilization of the treated milk and the expected degree of automation. Generally it is not part of a standard milk processing line.

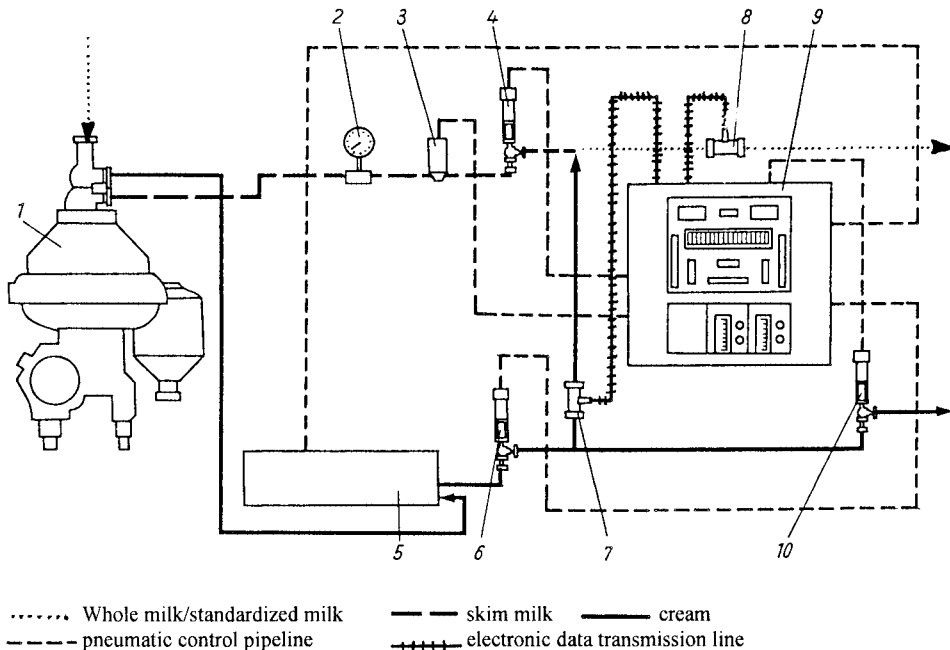


Figure 4./21 Automatic standardization device

(1) Separator (2) Pressure gauge (3) Pressure sensor (4) Regulating valve (5) Specific density device (6) Regulating valve (7) Flowmeter sensor (8) Flowmeter standardized milk (9) Control panel (10) Regulating valve

The membrane techniques which are used here permit a protein standardization as well as concentration and selection of individual milk components. In addition, this technology is utilized in other dairy technology processes. In this section, only basic explanations of membrane filtration will be given in order to better understand other applications which will be described later.

4.2.5.2.1. Basics of membrane filtration (membrane technique)

Membrane filtration can be applied industrially for the following purposes:

- Concentration Concentration of a soluble substance by extracting the solvent.
- Diafiltration Desalination of a solution by addition of a pure solvent (water); salts and lactose are extracted during the process.
- Fractionation Separation of molecules having significant differences in size and mass.

- Membrane filtration is a separation process in which the process liquid passes in parallel over a membrane through the installation. The membrane rejects components (which are transferred downstream with the process liquid) and thus maintains its permeability for a long time and blockages are avoided.

In regard to utilization, membrane selection, and process design, we distinguish between:

- Ultrafiltration
- Reverse osmosis
- Electrodialysis

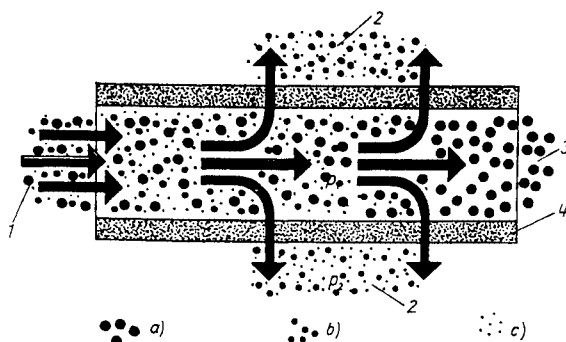
4.2.5.2.2. Ultrafiltration

This process is used to a great extent, as it can be applied for technical and economic reasons in several major and auxiliary processes in dairy technology.

- Ultrafiltration (UF) is a separation process in which, by using a pressure drop over membranes with small pores, water and dissolved smaller molecules migrate, whereas colloidal and larger molecules are retained and concentrated (Figure 4./22).

Figure 4./22 Principle of ultrafiltration

a) Macromolecules b) Small molecules c) Water
 (1) Process liquid inlet (2) Permeate (3) Concentrate (4) Membrane $p_1 > p_2$



Liquid with the larger molecules is called concentrate or retentate; liquid with the smaller molecules is called ultrafiltrate or permeate.

Membranes. Capacity and utilization of a UF plant are influenced mainly by the type of membrane.

Material. For simple separation processes, cellulose acetate membranes are used; they are cost effective but limited with regard to mechanical, thermal and chemical stress as well as their application (pH range 3–8, maximum temperature range 40–55 °C). Other membrane materials are synthetic polymers (polyamide, polysulfone and polyacrylnitril/polyvinylchloride); membranes made from these materials are more expensive but they have better characteristics. (pH range 1–13; maximum temperature range 85–100 °C) and have a wider utilization spectrum.

Structure. The membrane structure is mostly independent of the material. There are symmetric membranes in which the filter layer goes through the entire cross section and the products to be separated are retained only in the core of the membrane (so-called depth filtration). There are also asymmetrical membranes (having a porous frame structure, which has nearly no effect on the material transport, and the active filter layer proper).

(Figure 4./23). As the flow rate is inversely proportional to the membrane thickness, the asymmetrical membrane has higher flux and is therefore preferred in ultrafiltration.

Separation limits. The separation limit is an expression for the retention effect, i.e., from which molecular mass level the dissolved components are retained, and is controlled by the pore diameter and the pore distribution of the membrane. The membrane can have a very defined separation limit, with all components higher than a defined molecular mass retained while those with a lower molecular mass permeate. Or the membrane can have a diffuse separation limit, where as well as high-molecular-mass components some compounds with a lower molecular mass are retained which should pass through the membrane under normal conditions. Pore diameters of 5–50 nm are selected for molecular masses of milk proteins of 20–100,000 kg/mol.

Designs. Individual membranes are assembled into modules which form the outer shape. The packing density is one characteristic (i.e., how many square meters of active filter surface are effective in 1 m³ of filter material). According to the plant capacity, a corresponding number of modules are assembled in frames which then forms the entire unit. The following types exist:

- Tubular modules An asymmetric membrane is inserted into a large-pore plastic or stainless steel pipe with a diameter of 20–25 mm. The process liquid is pumped through this pipe at pressures of 3–10 bar, and the permeate exits on the side. The low packing density is a disadvantage.
- Plate modules These are built in round or elliptical form, and the membranes are mated with the carrier plates in a laminate type (Figure 4./24) which functions as an inlet and outlet of the pipe. The flow is similar to that in a plate heat exchanger. Advantages are easy replaceability of the membranes and low height of the installation. The packing density is in the range 100–400 m²/m³.
- Capillary tube Capillary tubes membranes (Figure 4./25) with an inner diameter of 1.1 mm are assembled into a module (the principle is shown in Figure 4./26). The advantage is low hydrostatic pressure during operation of the modules which permits the utilization of standard dairy pumps. Cleaning is easily accomplished by simple backflow or recirculation of the cleaning liquid.
- Spiral module The membrane, the permeate-carrying layer, the separating layer (serving to maintain the distance) and the layer carrying the process liquid are stacked into layers over each other, and wound around a perforated permeate-collecting pipe (Figure 4./27). The process liquid flows laminar in an axial direction through the module, whereas the permeate in the separating layer flows in a spiral fashion to the concentrically installed collecting pipe.

Capacity. Flux is defined as the permeate flow V in l/h, passing through a membrane of 1 m². Other terms are mass flow m in kg/h/m², or daily capacity l/day/m². Furthermore, terms like “specific membrane capacity” or “specific flow rate” are used. In actual operation flux is in a range of 20–50 l/h per m² filter area. It depends on density, viscosity and liquid pressure. Some values for osmotic pressure are shown in Overview 4./3.

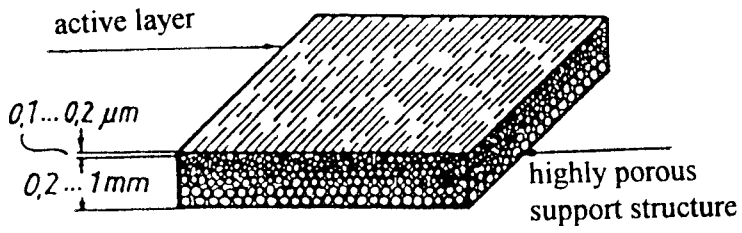


Figure 4./23 Structure of an asymmetric membrane

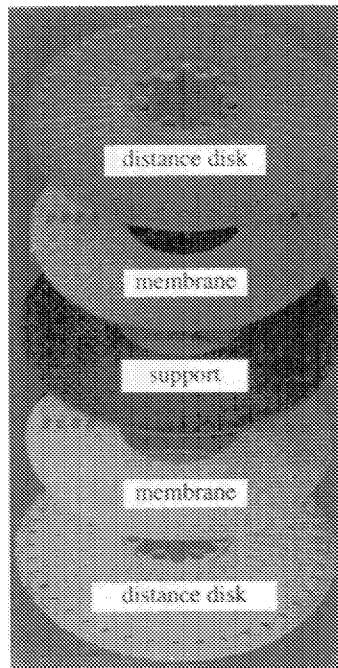


Figure 4./24 Structure of a plate module

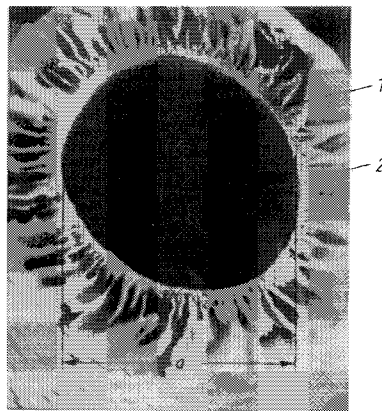


Figure 4./25 Capillary tube membrane

(1) Active layer (2) Support layer

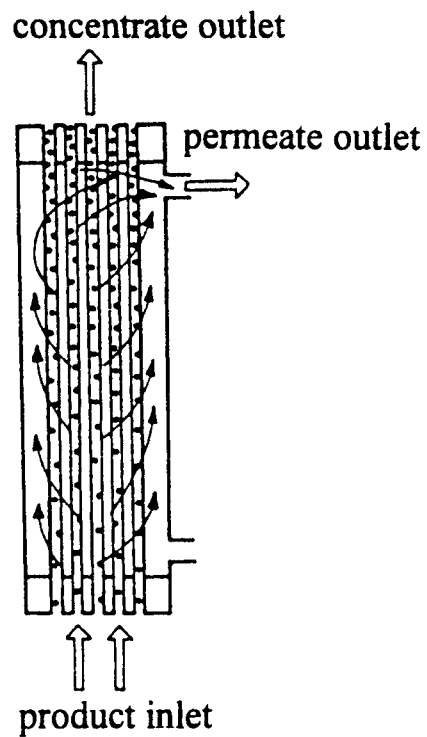


Figure 4./26 Principles of a capillary tube module

Membrane diameter about 1.1 mm

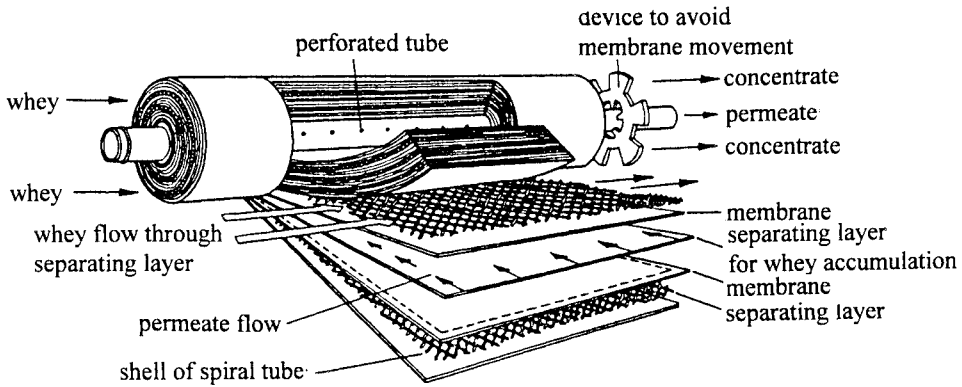


Figure 4./27 Design and principle of a spiral module

Flow conditions. with a relatively high liquid velocity and the laminar flow (close to the inner surface), high molecular-weight particles are deposited on the membrane surface create a coating. This results in superconcentration on the membrane, and deposited particles can rediffuse into the liquid flow. This coating increases until an equilibrium is created between flow and backflow of the dissolved particles. Increasing the flow velocity results in a reduced coating and thus improve the flux and the discharge of the retained particles. However, there product-specific, constructive and economic limits to an increase in fluid velocity. The coating layer can be removed by a permeate backflow or a cleaning process. The influence of process variable parameters is shown in Figure 4./28.

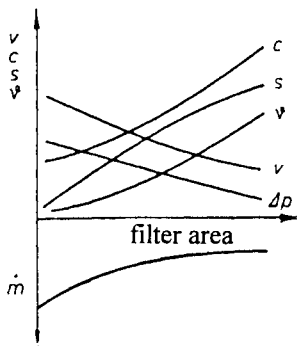


Figure 4./28 Process parameters during membrane filtration

- m mass flow
- v fluid velocity
- c concentration
- η viscosity
- Δp hydrostatic pressure difference

Ultrafiltration plants. These plants can be configured for either batch and continuous operations. In a batch-type process (discontinuous) a preset quantity of the process liquid is pumped from a storage vessel through the UF modules until the desired final concentration is achieved. This process is used mainly for small fluid volumes and for laboratory purposes.

In a continuous operation (industrial scale), the process liquid is pumped through several modules—set up in series—and leaves the installation with the desired concentration (Figure 4./29). The capacity of the installation can be increased by adding more modules(in serial or parallel flow mode).

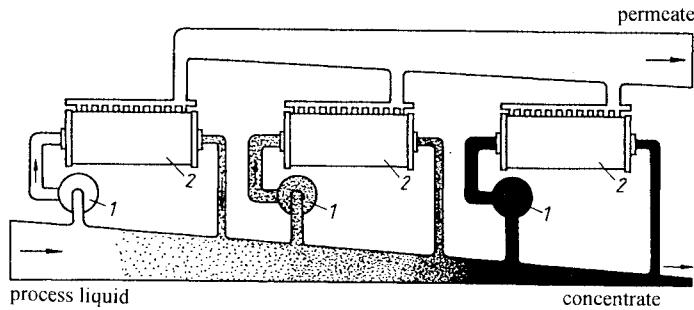


Figure 4./29 Principle of a continuous-type UF installation

(1) Product pump (2) UF module

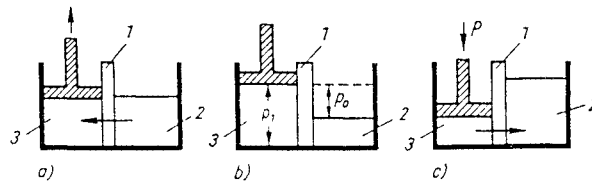


Figure 4./30 Principles of Reverse Osmosis

a) Osmosis; a diluted solution (water) diffuses into a more concentrated solution, thus reducing the concentration b) Concentration equalization; $p_0 = p_1$, diffusion stops c) Reverse osmosis; using an external pressure $p > p_0$, water leaves the solution and the concentration level increases
 p external pressure p_0 osmotic pressure p_1 hydrostatic pressure

(1) Semipermeable membrane (2) Diluted solution or water (3) More concentrated solution

Overview 4./3 Differences between reverse osmosis and ultrafiltration ¹

Properties	Reverse Osmosis	Ultrafiltration
Size of retained molecules mass M in kg/kmol	$M = 5000$	$M = 1000$
Osmotic pressure of the concentrate in bar	7–85	0.6–7
Type of membrane effect	Diffusion barrier, molecular effect possible (pore size about 0.4 nm)	Molecular sieve effect (pore size 2 nm)
Chemical composition of	Important for influencing the mass transport	Not important for influencing the mass transport, as long as pore size and distribution are maintained.

¹According to Sienkiewicz, T.: Riedel, C.-L.: Molke und Molkeverwertung. Leipzig: VEB Fachbuchverlag, 1986.

4.2.5.2.3. Reverse Osmosis

Reverse osmosis (or hyperfiltration) is a separation process like the ultrafiltration, but here smaller pore, semipermeable and only asymmetric membranes are used. They retain dissolved components like salt and lactose at a level of 80–99% and permit only the passage of water molecules in the form of a permeate. The basic differences between reverse

osmosis and ultrafiltration are shown in Overview 4./3. The operating principle of reverse osmosis is shown in Figure 4./30.

If two solutions are kept separated by a semipermeable membrane, there is an equilibrium if the concentrations are equal on both sides. If on one side of the membrane there is a concentrated solution and on the other side there is a diluted solution, the solvent permeates into the concentrated solution because of the higher osmotic pressure of the concentrated solution. The concentrated solution is diluted until the newly created hydrostatic pressure is equal to the osmotic pressure.

The solvent transport can be stopped when an external pressure is applied. If this external pressure is higher than the osmotic pressure, the solvent flow is reversed. Pure solvent then flows from the concentrated solution into the diluted solution.

4.2.5.2.4. Electrodialysis

Electrodialysis is a separation process based on electrolysis.

- Electrolysis¹ is the decomposition of electrolytes (acid, base, salt) in an aqueous solution by using an electric current in which cations are deposited on the anode and anions are deposited on the cathode.

During electrolysis the same effect is achieved; however, ion-selective membranes avoid deposition and therefore permit continuous flow of the process liquid. A concentrate and a demineralized solution (Figure 4./31) are obtained.

4.2.5.2.5. Gelfiltration

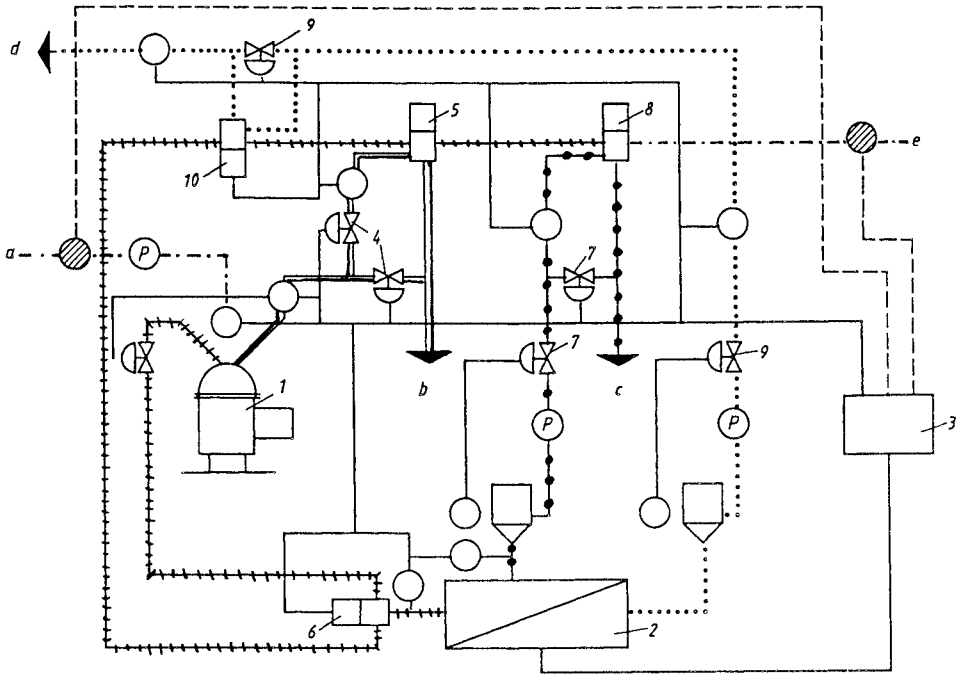
Another possible method for separating protein fractions from milk or a lactose-salt fraction is gel filtration (Figure 4./32). In this process, gel spheres are filled into a cylindrical column with a cone at the bottom; these gel spheres consist of a strongly hydrophilic three-dimensional lattice. The liquid (e.g., whey) is poured into the column and the smaller lactose and salt molecules penetrate into the rehydrated gel spheres and are retained. The larger protein molecules cannot penetrate into the pores and therefore bypass the gel spheres.

Compared to ultrafiltration on an industrial scale, gel filtration has a few disadvantages such as higher water consumption, expensive gel material, difficult regeneration and required preconcentration, resulting in applications which require only highly purified protein fractions.

4.2.5.3. Processes for the fat and protein standardization

Fat standardization can be combined with protein standardization (see Figure 4./33). Here the fat and protein content of raw milk as well as the intermediate products (cream, skim milk, concentrate and permeate) and standardized milk are determined continuously with sensors, and the data are continuously processed in a computer, resulting in control parameters. The determinations can be done batchwise using standard methods, and the results are fed manually into the computer.

¹ Dialysis: separation of low molecular particles from colloids by using semipermeable membranes.



- ⊙ (P) Product pump
- ⊙ (hatched) Sensor for fat and protein level
- ⊙ (white) Sensor for flow rate
- Whole milk/standardized milk
- ++++ Skim milk
- Concentrate
- Permeate
- Control circuit for volume flow
- Control circuit for fat and protein level
- == Cream

Figure 4./33 Automatic fat and protein standardization plant

a) Milk infeed b) Cream discharge c) Concentrate discharge d) Permeate discharge e) Discharge for milk, standardized on fat and protein

(1) Separator (2) UF plant (3) Microcomputer (4) Regulating valve (5) Mixing valve for cream (6) Three-way valve for discharge of skim milk partial flow (7) Regulating valve for concentrate quantity (8) Mixing valve for concentrate quantity (9) Regulating valve for permeate quantity (10) Mixing valve for permeate quantity

4.2.6. Bactofugation of milk

- Bactofugation is a special form of separation in which specific types of microorganisms (mainly spore-forming bacilli) are removed from milk and inactivated thereafter.

Generally all active (vegetative) microorganisms are inactivated by pasteurization (as described in Section 4.2.7) to such an extent that both hygienic and technological requirements are met. However, the highly heat-resistant spores are surviving the pasteurization process as precursors of spore-forming bacilli and clostridia. Spores can form new vegetative cells by growing under favorable conditions and then propagating very rapidly. They can lead to significant quality defects in hard cheese, semihard cheese or long-life

products due to proteolysis, lipolysis and gas formation. Therefore bactofugation is used mainly in the manufacture of these product groups.

Technology. Bactofuges are special nozzle clarifying separators with high separation precision that can remove microorganisms from milk based on their higher density. This is applicable especially for spore-forming cells or spores, as the density difference from milk is enhanced by the concentrated cell plasma of the spore, and it permits complete separation of this group of microorganisms by a bactofugation.

Design and operating principle of a bactofuge (Figure 4./34). Separated microorganisms are concentrated on the periphery of the bowl, are transported in milk highly enriched with bacteria (bactofugate) to the outside via the nozzles (1), and are then collected in the sludge discharge pipe (2). The bactofugate, which still corresponds to 2–3% of the treated milk, is transferred into a cyclone (3), deaerated and transferred toward the discharge. The air, highly contaminated with microorganisms, goes into an overflow (5), avoiding the contamination of environmental air. The relatively high quantity of bactofugate must be treated in such a way that all microorganisms are inactivated the milk must be used suitably.

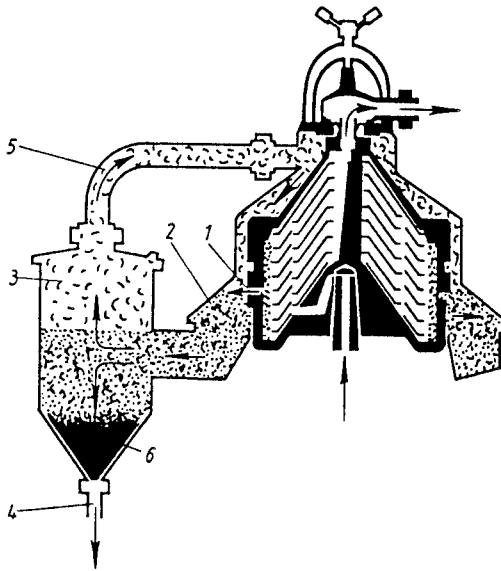
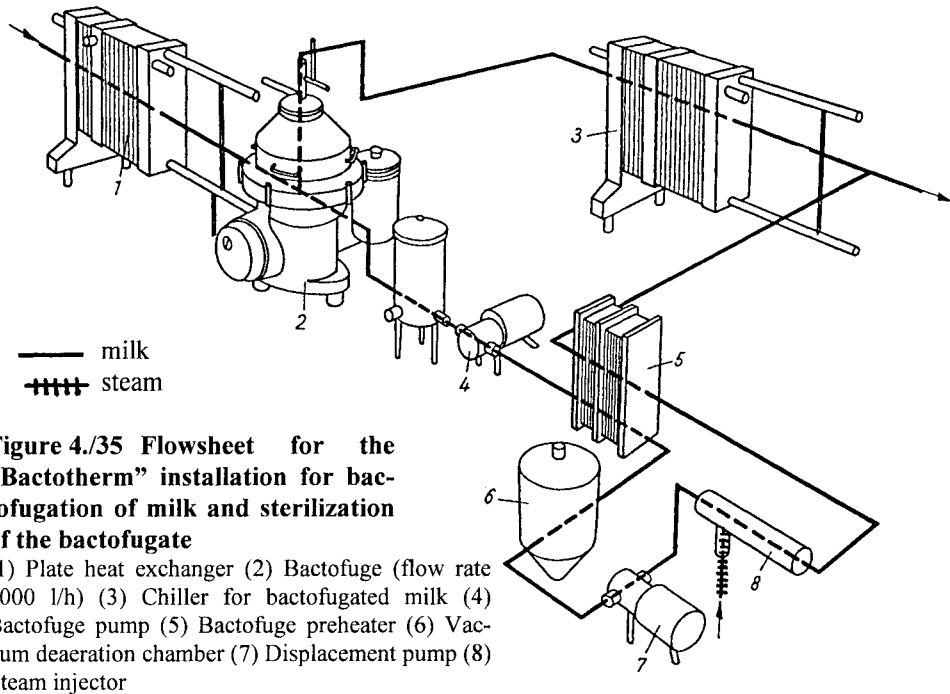


Figure 4./34 Hermetic bactofuge, type D 3187 M

(1) Nozzles in the bowl wall (2) Sludge discharge bend (3) Cyclone discharge (4) Discharge for bactofugate (5) Overflow for germ-enriched air (6) Bactofugate

Bactotherm processes (Figures 4./35). Clarified and standardized milk is pumped into a plate heat exchanger (1), where it is heated up to the bactofugation temperature of 60–75 °C, and into the bactofuge (2). Then it is pasteurized in a plate heat exchanger (3) and rechilled for further processing. The bactofugate is transferred by means of a pump (4) into another preheating section of the plate heat exchanger (5), then into the vacuum deaerator (6), and from there by a pump (7) into the steam injector (8). The bactofugate enters the injector head through a perforated pipe and is mixed with steam (130–140 °C, 3 bar, residence time 3–4 seconds). This time-temperature profile is sufficient to inactivate all spores. The sterilized bactofugate is rechilled in the plate heat exchanger (5) and can be added back into deaeration milk or discharged separately for other suitable applications.



4.2.7. Heat treatment of milk

Thermal treatment is an energy transfer of heat into milk. Heat treatment is often referred to as “heating,” leading to terms of heat treatment processes (see Section 4.2.7.2). Just by looking at the formulas for energy quantities (see 4.2.7.3) we realize which energy requirement is necessary for heating the milk and why these processes merit such importance.

The objective of the heat treatment is to completely inactivate all microorganisms which are contained in milk. This results however—whether desired or not—in a modification of the natural milk components, especially inactivation of the enzymes found in milk. Primarily, heat treatment is a hygiene-oriented activity within the entire framework of processing. On the other hand, it is a dominant factor for improving the shelf life of all fresh milk products and is a legal obligation. The most common thermal process, not only in dairy technology, is pasteurization.

- Pasteurization is the thermal inactivation of microorganisms at temperatures below 100 °C, which improves the hygienic quality of food and achieves a certain level of preservation.

The main objective is to inactivate pathogens in order to avoid a health hazard for human beings and animals. At the same time, a significant reduction of the total count is a good base for further processing of milk into a multitude of products. Apart from the hygiene aspect, gentle heat treatment must be achieved which results in time-temperature profiles meeting the following requirements:

- a) The inactivation effect (percent of inactivated microorganisms) has to be >99%; for pathogenic germs it must be 100%.

- b) Milk must be treated gently in order to retain the maximum amount of nutrients and vitamins as well as the organoleptic quality.
- c) Process economics must be profitable, and the installation costs must be low.

Alternative processes for the heat treatment. Other processes are known for the reduction of the germ count in milk. The removal of microorganisms by bacto-fugation was discussed in Section 4.2.6. For the inactivation of microorganisms, other processes should be mentioned such as:

- a) *Radiation with UV, X-rays or gamma-rays.*
- b) *Ohmic heating.* The product is the electrical resistor in the circuit, especially for highly viscous material.
- c) *High-pressure process,* using pressures of 2000–6000 bar and temperatures of 40–60 °C.
- d) *Ultrasound process.*
- e) *Microwave treatment.*

The last process is a very interesting one for the thermal treatment of foods. When heating with microwaves, the product is exposed to an electromagnetic field having a frequency of 800–3000 Hz. The heat is caused by the rotation of the dipoles and oscillation of ions in the food. The microwave energy is created by transforming a current in a generator (magnetron or klystron), from which the microwaves are fed through a rectangular channel (to conduct the waves) into an applicator and heat treatment unit. The product enters the sealed and protected chamber, and the microwaves are fed into it (with an antenna, slit and/or other sharp inserts and other facilities for distributing the microwaves), and penetrate the food evenly. It is recommended that milk be pasteurized at 65 °C and 30 min residence time.

These processes are not yet widely applied. Their main disadvantage are their low inactivation effect, legal barriers, and high costs, and they also result in very noticeable organoleptic modifications of the milk.

In a review of how to best meet the (primarily) hygienic requirements, thermal treatment with steam or hot water is still an acceptable compromise and will be discussed in detail hereafter.

4.2.7.1. Influences during the heat treatment

The inactivation effect and the chemical-physical, nutritional and organoleptic changes in milk during heat treatment are characterized by the following parameters:

- a) Temperature and time (time-temperature profile)
- b) Type of microorganisms and initial level of contamination
- c) Acidity of milk
- d) Flow conditions and heat transfer in the installations

Time and temperature. Regarding microorganism inactivation, there is a nearly logarithmic relationship between temperature and time for a given range (see Figure 4./38). If temperature is increased by 10 °C, the bacterial level is reduced to 1/10 of the initial level. If we assume that for a total inactivation of the microorganisms in milk at 100 °C a time of 30 minutes is required, we obtain the following residence times when temperature is increased by 10 °C:

100 °C = 30 min	130 °C = 1.8 s
110 °C = 3 min	140 °C = 0.18 s
120 °C = 0.3 min or 18 s	

The quotient, which expresses the decrease in inactivation time when the temperature is increased by 10 °C is called the Q_{10} factor. This value indicates how much the time for a complete germ inactivation is reduced when the temperature is increased by 10 °C. The Q_{10} factor for microorganisms is 9–13, for sporeformers about 30. If a type of bacteria is inactivated at 11.5 times more rapidly at 90 °C than at 80 °C, then the Q_{10} -factor is 11.5. The velocity of chemical reactions in milk increases by a factor of 2–4 when temperature is increased by 10 °C; the physical changes increase by a factor of approximately 2.

Another indicator for complete inactivation (sterility) is the F value (see 9.3.1.5)

*Changes of milk components.*¹ The relatively low Q_{10} values for chemical and physical modifications appear to permit very high heat treatment for a short time; however, we have to consider modification of the milk components even with temperatures slightly above 70 °C and residence times of only a few seconds.

With increasing temperatures and residence times, whey proteins are modified; e.g., the solubility decreases to such an extent that they coagulate with casein at a pH of 4.6. Another consequence of the heat treatment of proteins is the liberation of sulfhydryl groups (SH- groups), thus increasing the antioxidative properties of the milk and leading to the development of a cooked taste. At the same time, we observe a percent decrease of whey proteins and a quantitative increase of casein. In particular, we observe complex formation between κ -casein and β -lactalbumin, resulting in an additional protective colloidal effect. This results, e.g., in delayed release of the peptides when the lab enzyme is added to milk during cheese manufacture, leading to a significant delay of the enzymatic precipitation. On the other hand, a firmer gel is created due to the concomitantly increased water-binding capacity of the proteins with reduced syneresis (see 7.3.3.1), which is favorable in the manufacture of yogurt but impedes the release of whey during cheese manufacture. Casein remains nearly unchanged at normal pasteurization temperatures.

The heat treatment also leads to a more or less pronounced disturbance of the salt equilibrium in milk. Soluble calcium and phosphorus are bound in calcium phosphate, which precipitates on the casein micelle. This activity is reversible up to a temperature level of 80 °C; at higher temperatures, calcium precipitates and forms stonelike deposits on the heat exchange surface of machines.

Longer residence times at temperatures >100 °C can lead to complex compounds between casein and lactose. The observed browning of such treated products is called the Maillard reaction. At this temperature level nearly all enzymes are inactivated, and vitamin losses of 20–30 % are observed. But even at lower temperatures, more or less significant vitamin degradation must be foreseen, especially for the B complex.

Heat treatment has only a minor effect on fat. Only the membranes of the fat globules with their heat-sensitive protein compounds experience some modifications, influencing the agglomeration of fat globules and their creaming.

¹ A wide range of work has been done by Prof. H.G.Kessler, Technische Universität München-Weihenstephan.

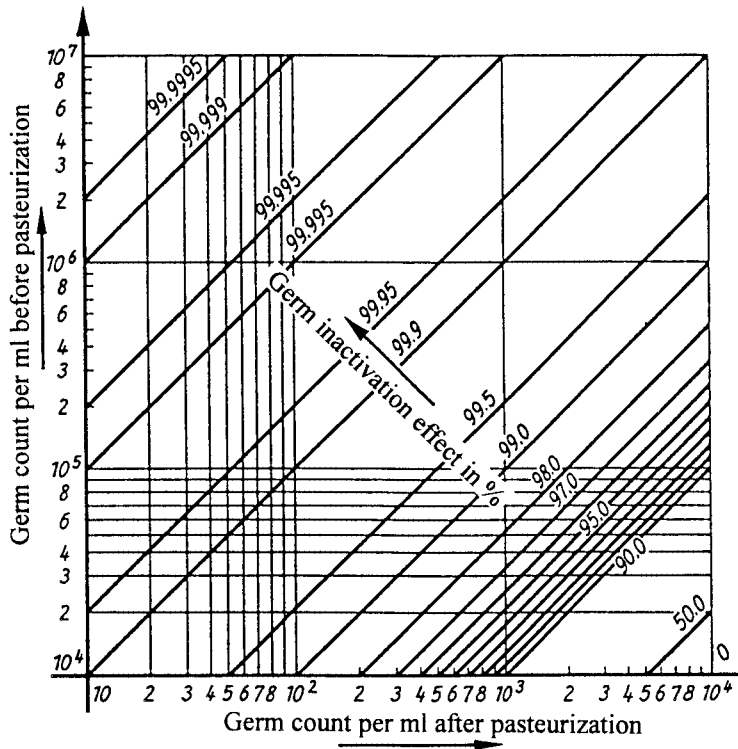


Figure 4.36 Germ inactivation effect during pasteurization

Types of microorganisms and initial level. The germ inactivation effect depends largely on the type of microorganisms which can be found in milk. Most of the vegetative forms, especially the lactic acid bacteria, and pathogens are inactivated at temperatures of 70–90 °C and residence times of a few seconds to a few minutes. Excluded are the thermophilic lactic acid bacteria which can survive slightly higher temperatures, and the spores of surviving bacilli for which temperatures >100 °C are necessary. The time required for germ inactivation is a function of the total count, and the initial count determines the total count of the milk which is to be treated (Figure 4.36).

Heat transfer in machines (Figure 4.37). If heat passes from a liquid medium M_1 to another medium M_2 through a wall with a thickness s_1 , the process is called heat transfer, and it consists of both heat transfer (convection) and heat conduction.

heat transfer from M_1 to the left area (heat transfer I)
 ↓
 heat conduction through the wall
 ↓
 heat transfer II from the right area to M_2

A closer look shows a liquid boundary layer (1) on the wall with lower fluid velocity, which is also called Prandtl's boundary layer. Here we have laminar flow and the heat transfer is in the form of heat conduction.

Outside this boundary layer we observe turbulent mixing (turbulence) and more rapid temperature equalization, so that the temperature is nearly the same everywhere (t_1 or t_2). The entire temperature drop occurs within this boundary layer, and the heat transfer num-

ber α indicates the quality of the heat transfer in this layer. Therefore the objective during heat transfer is to have very good turbulence in the medium.

Heat transfer depends upon the type of flow and other factors. These include the specific heat conduction number λ of the material ($\lambda_{\text{Steel}} = 30\text{--}45$; $\lambda_{\text{Water}} = 0.50$; λ_{Air} at $0^\circ\text{C} = 0.022$), temperature differences of the media, wall thickness s_1 and the fluid velocity. The heat conduction number can be calculated from these parameters.

The heat transfer number can be reduced significantly by burning and stone-like deposits of milk components on the heat exchanger surfaces, incorporation of air into the milk and too low high fluid velocities of the heating media, and this results in a reduction of the microorganism inactivation.

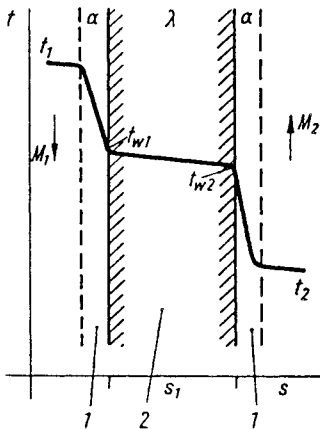


Figure 4.37 Heat transfer in a machine

(M_1) Medium 1, (M_2) Medium 2, (s) Distance, (s_1) Thickness of the wall, (t) Temperature at the wall (t_{w1}) and (t_{w2}) Temperature of the medium (t_1) and (t_2), (α) Heat transfer number, (λ) Heat conduction number (1) Boundary layer (2) Wall

4.2.7.2. Heat treatment processes

In view of the requirements for heat treatment and modifications, which can be assumed in milk, time-temperature profiles have been established for heat treatment processes and are shown in Overview 4./4.

The holding time of those temperatures is a function of the residence time in the heating section proper of the installation, where milk reaches the preset temperature due to heat transfer, as well as residence time of a postheating holding section, where no heat transfer takes place. The time-temperature combinations of the heating process for milk are shown graphically in Figure 4./38. The influence of the individual technologies on microorganisms and chemical changes of milk is shown in Figure 4./39. Which process must be selected for an actual application is governed primarily by the products as well as legal requirements.

The short-time treatment guarantees relatively gentle milk treatment and is the most widely applied system. Due to the large-scale requirements, the low-heat, long-time treatment is without any industrial significance.

Thermization is used mainly for heat treatment of raw milk in order to stabilize its quality during longer storage by inactivating psychrotrophic microorganisms (see Section 2.3.3.3). However, additional processes are required.

The high heat process is used mainly for heating of cream. It is also used eventually for a very low quality of raw milk. The high heat process with direct steam injection is used in order to increase the shelf life of fresh milk under conditions similar to those for the short-time process. This process is also used for cheese milk and milk concentrates for long-shelf-life products.

Overview 4./4 Heat treatment processes

Type	Temperature range in °C	Holding time for heat effect		Probable inactivation effect in %	Confirmation method	Remarks
		Heating	Holding			
Thermization	57-68	min. 15 s	without	< 95	phosphatase positive	thermization process for raw milk and cheese milk
Batch method	62-65	8-12 s	30 min	= 95	phosphatase positive	batchwise heating
Short time	71.7-74	8-12 s	>=15 s	99.5	phosphatase negative peroxidase positive	pasteurization with indirect heat transfer
High heat	85-90	8-15 s	without	99.9	peroxidase negative	pasteurization with indirect heat transfer
High pasteurization	ca. 125	0.71 s	without	up to 100	peroxidase negative	high heat with direct steam injection in heating section
Ultra-high heat	135-150	>=1 s (2-8 sec)	without	up to 100	peroxidase negative	with direct or indirect heat transfer
Sterilization	109-115		20-45 min	100		indirect heat transfer;

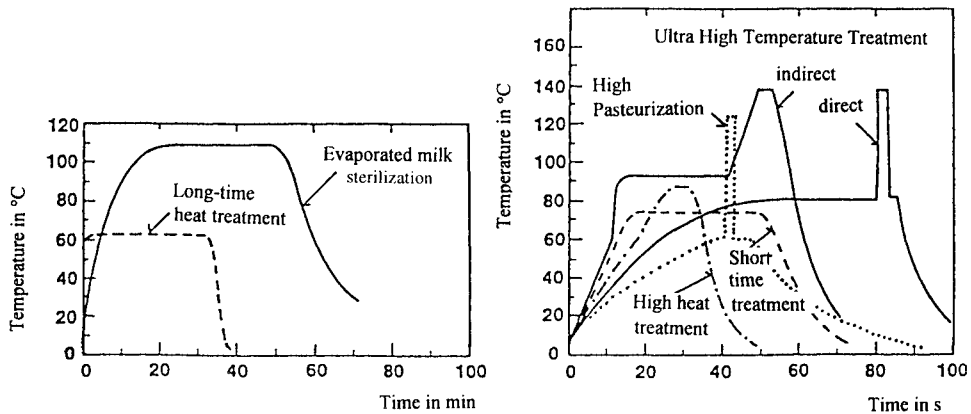


Figure 4./38 Time-temperature profiles for heating processes

Using the ultra high temperature (UHT) process leads to organoleptic changes in milk without changing the nutritional value significantly. This process, with direct or indirect heat transfer, is used mainly for the manufacture of UHT milk. Sterilization is used only, when filled products must be preserved for a period longer than 5 months.

Heat treatment processes can also be used in combinations. A thermization or a short-time heat treatment can be used before applying a high-heat pasteurization, ultra-high heat treatment or sterilization.

Sterilization leads to a completely sterile product. The high-heat pasteurization and ultra-high heat treatment achieves a “commercial” sterility; i.e., the product is free of microorganisms which can grow, causing a spoilage of the product or illnesses.

Confirmation of heating. Proof of the proper heat treatment must be established in two different ways. One way is by recording the temperature; the charts have to show the date,

and they must be kept for 2 years. Not included in this requirement are short-shelf-life products; in this case the storage period for the records is shortened to 2 months after expiration or minimum shelf life date.

The second test is a negative enzyme test. If the high heat treatment process is done properly, then the enzyme *peroxidase* (inactivated at temperatures $\geq 85^\circ\text{C}$) is absent; if a short-time heat treatment is applied, the enzyme *alkaline phosphatase* is absent (inactivated at temperatures $\geq 71^\circ\text{C}$).

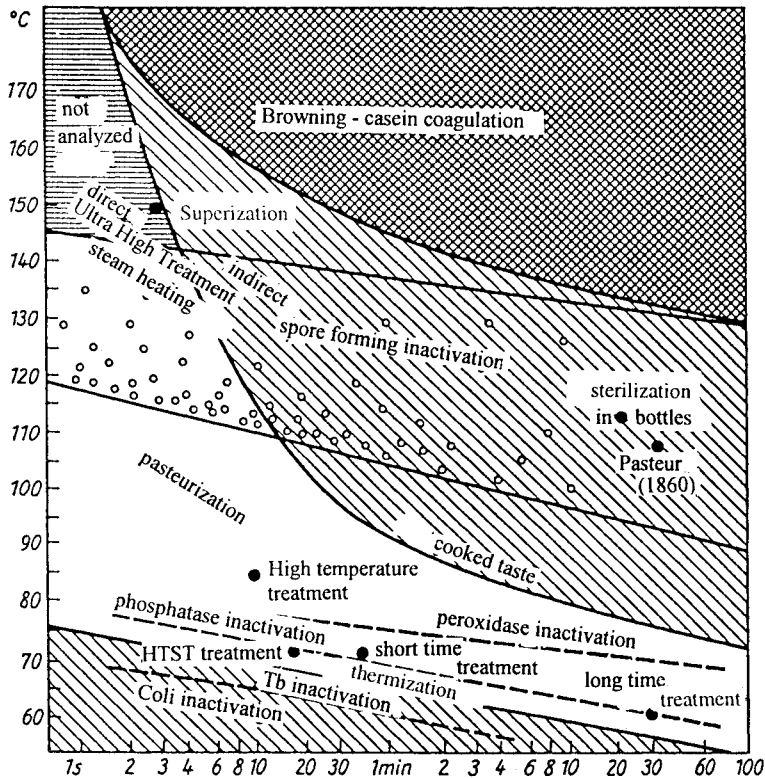


Figure 4./39 Influence of the heat treatment process on the milk quality

4.2.7.3. Equipment and installation for heat treatment

Here we present only installations for pasteurization and ultra-high heat treatment; installations for sterilization are described in the section long-shelf-life products. Each heat treatment installation must be approved or certified by the corresponding authorities and must include legally prescribed minimum equipment. This includes:

- a) Automatic temperature control and recording devices.
- b) Automatic safety device to avoid insufficient heating of the milk (bypass installation) with recording device for time/temperature and valve position for the flow, as well as passage and recirculation of the milk or cleaning.
- c) Safety device with automatic recording against unplanned blending of pasteurized or sterilized milk with nonheated milk, based on pressure increase after the heating or holding section of the heat exchanger.

Further each machine must have a plaque, which indicates the manufacturer, type, serial number, capacity, heat treatment and certification number. The heat transfer (see Overview 4./4) can be done in a direct way by blending two different media or in an indirect way, where the media are separated by a wall. The heat transfer can take place between media in a vapor state and a liquid state or between two liquid media. The basis is a temperature difference between the two media. The energy quantity which is required, to raise the mass of a material to a defined temperature is calculated as follows:

$$W = m \cdot c(T_2 - T_1)$$

If the mass is linked to a time unit, then we have the heat flow

$$\Phi = \dot{m} \cdot c \cdot \Delta T$$

Φ	energy quantity in J or kcal	W	energy flow W
m	mass in kg	c	specific heat in J/kg · °K
T_1	lower material temperature in °C	T_2	higher material temperature in °C
ΔT	temperature difference $T_2 - T_1$ [°K]		
\dot{m}	mass flow in kg/s		

The mass can be replaced by volume, and then we obtain the volume flow V in m^3/s or, as is usually indicated, in l/h.

The most widely used installations for the heat treatment of milk are plate heat exchangers. For reasons related to the flow conditions, tubular heat exchangers are used when operating at temperature levels > 100 °C, e.g., in ultra-high heat treatment. Plate heat exchangers are designed in a modular form; i.e., all sections required for the pasteurization process are installed in a frame. Individual sections are installed in such a way that the hottest section is followed by the section at the next lower temperature, resulting in thermodynamic advantages. The following guidelines should be maintained (considering accepted deviations) when operating a plate heat exchanger:

Steam pressure	1.01–1.03 bar
Hot water inlet temperature in heating section	at 65% heat recovery 3–4 °K above milk outlet temperature; at 80% heat recovery 2–3 °K above milk outlet temperature
Flow rate tolerances	short time +5 to –10% high heat +10 to –30%
Temperature tolerance (compared to calibrated thermometer)	0.5 °K
Recording tolerance (compared to calibrated thermometer)	0.5 °K
Deviation to temperature indicator	0.2 °K
max. difference of control input at setpoint for rising or falling temperature	1.0 °K
Max. temperature tolerance at setpoint	+5.0 °K
Stabilization time after exceeding temperature during start-up	120 s
Time for switch-over activity	max. 3 s

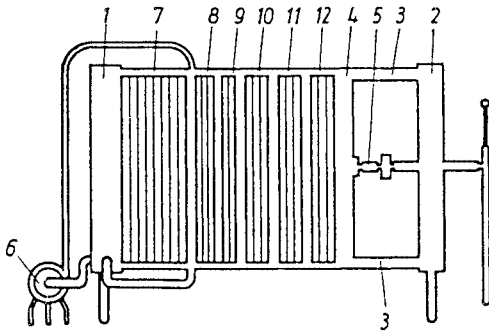


Figure 4./40 Plate heat exchanger type PA 500/100 for short-time heating of milk, flow rate 10,000 l/h

- (1) Back base (2) Front base (3) Guiding rail (4) Pressure plate (5) Central screw (6) Pump for pressure increase for return flow (7) Holding section (8) Heating section (9) Heat exchanger II (10) Heat exchanger I (11) Precooling section (12) Cooling section

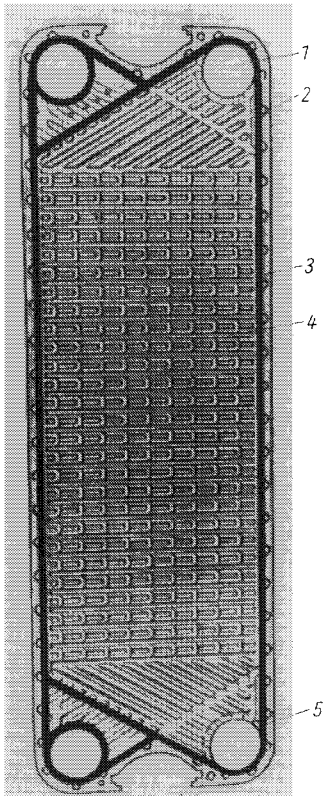


Figure 4./41 Single flow plate type PA 5; heating surface 0.4 m², weight 3.5 kg, liquid surface volume between plates 2.35 dm³, pressure tested to 10 bar, connections 65 and 80 mm

- (1) Inlet (2) Flow profile and channels for uniform liquid distribution (3) Gasket (4) Ribs for creating turbulence (5) Outlet

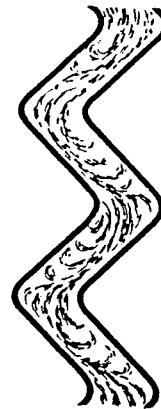


Figure 4./42 Turbulence between plates

Design and operating principle of a plate heat exchanger. The configuration of the individual sections of a plate heat exchanger is shown in Figure 4./40. Several heat exchange plates are assembled and are installed sectionwise in a frame. In many cases plate heat exchangers for short-time heating have no holding section, but they have a tubular holding pipe (see Figure 4./53) besides the plate heat exchanger. This makes it possible to keep plate heat exchanger very small and space efficient.

Heat exchanger plates. Heat exchanger plates such as the single flow plate (Figure 4./41) are made from stainless steel—as other heat transfer plates—and have a heating surface of 0.2–0.4 m². A relatively large surface, considering the overall dimensions, is achieved by the fishbone-like pressed surface pattern. At the same time, very good turbulence is achieved between the plates (Figure 4./42), thus creating nearly identical heat transfer conditions for all product particles, and a different thermal load is excluded. Close to the passage openings and between the fishbones, distance holders are shaped into the plates, which maintain a uniform distance between the plates. Additional longitudinal-shaped cams in the area of the inlet serve for good product distribution over the entire surface of the plate.

Sealing the flows from each other and from the outside is done on the periphery of the plates and around the inlet/outlet openings with profiled gaskets, which are glued into the correspondingly shaped grooves. Further the plates are set up for hydrodynamic reasons in such a way that the inlet and outlet for the media are on the same side of the plate. This means that the inflow of the medium is on one side and the outflow is on the other side, resulting in simplified piping connections and reduced assembly costs.

- In each section, wherever there is heat transfer, one medium enters through the inflow and a second exits into the return flow.

In order to have a uniform fluid velocity between the plates and fluid distribution over the entire plate surface, the fluid velocity of the media must be ≥ 0.25 m/s. This fluid velocity depends among other things, on the flow rate and pressure drop. As the pressure drop decreases with longer distance, considerable pressure differences can be observed between the inflow and the outflow.

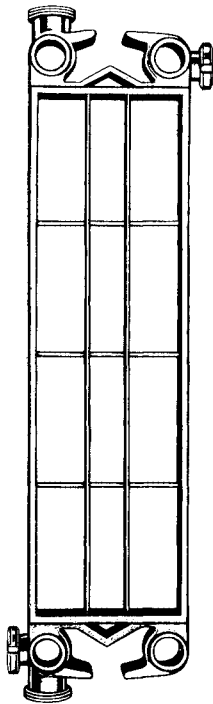


Figure 4./43 Connecting plate

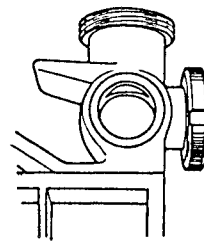


Figure 4./44 Connecting corner

Connecting plates (Figure 4./43). They are installed between the plate assemblies of the individual sections and separate them from each other. Connecting points, which can be replaced in most cases, permit the connection to other installations (Figure 4./44).

Flow patterns and circuits. A flow is formed between two plates of a plate assembly. By sequencing the various plates, flow patterns and stages are established in a section. Parallel flow patterns mostly form one stage. The stages are installed in series in a section. The number of parallel flows per stage and the serial stages are chosen according to circumstances; the heating and holding section should not be modified by the operator. A simple flow pattern is shown in Figure 4./45, another one is the flow of a plate heat exchanger for a short-time heat treatment (Figure 4./46). The description of the flow can be found in Section 4.3.

Heating in a plate heat exchanger. Heating is done with either steam or hot water, which is made by using steam. Constant pressure and temperature conditions in the steam supply pipes are the basis for a noninterrupted process. The choice of a correctly calculated pipe diameter of the steam pipe lines and effective pressure control are the basis for constant conditions. For heating purposes, saturated steam (no superheated steam) is used, which should have the quality of a wet steam (2–8% water content). Pressure should be 0.96–1.96 bar.

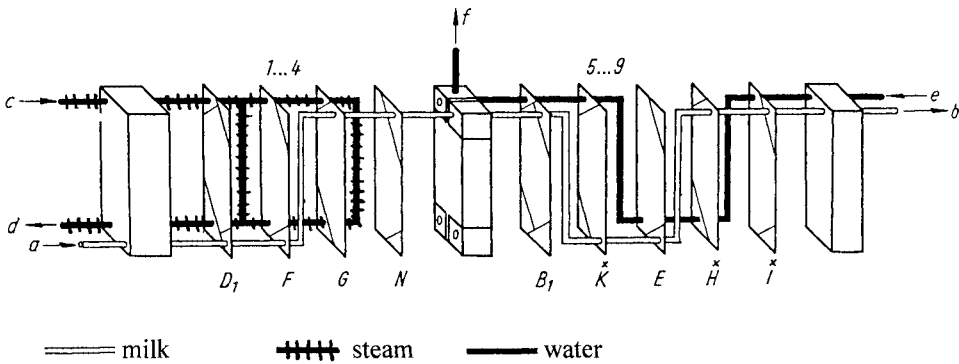


Figure 4./45 Heat exchange and flow directions in heat exchanger

a) Milk inlet, right side b) Milk outlet, right side c) Steam inlet, left side d) Condensate outlet, left side e) Water inlet, left side f) Water outlet left top
 D1, F, G and so on indicate the plates, 1...4 and 5...9 the number of plates.

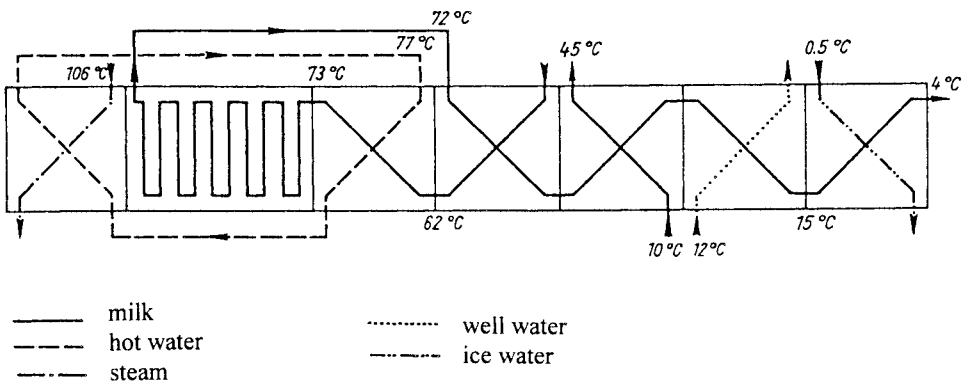


Figure 4./46 Flow pattern for a short-time heating and holding process

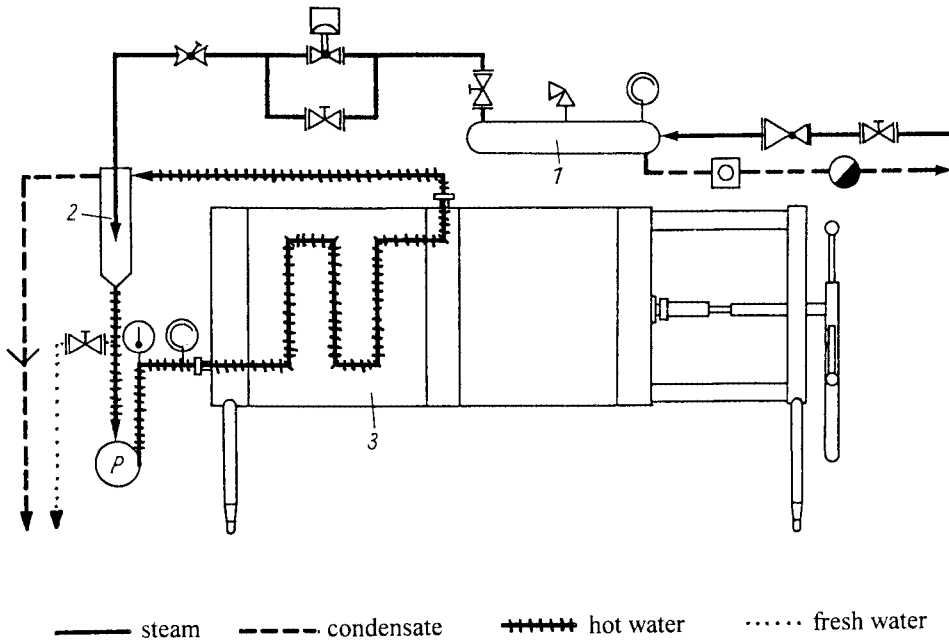


Figure 4./47 Heat supply to a plate heat exchanger for short-time heat treatment
 (1) Steam distribution (2) Mixing battery (3) Plate heat exchanger

Steam injection is used in plate heat exchangers both for the high-heat process and for heating cream. Due to the relatively wide differences between the steam temperature and the product temperature as well as the high steam temperatures ($>100\text{ }^{\circ}\text{C}$), the risk of burning milk is high, and therefore enhanced deposition in the heating section must be considered. Short-time heating and thermization use hot water, which can be obtained in three different ways:

- a) In a separate section of the plate heat exchanger
- b) In a mixing nozzle
- c) In a hot water battery

The flow in Figure 4./46 shows that the pressure-reduced steam passes through a membrane valve into the hot water mixing battery, where it is mixed with water. The membrane valve controls the steam quantity as a function of the set temperature (see 4.3.3), and the valve is actuated pneumatically, adjusting the hot water temperature accordingly. The steam distributor (Figure 4./47) can be eliminated if wet steam can be supplied directly from the steam boiler, as wet steam cools down along its way in the steam pipes. Steam is dried by pressure reduction; it does not superheat.

4.2.7.4. Capacity limitations

Flow controllers serve to maintain the tolerance limits for flow rates in milk heat treatment plants, and each processing line must have such a device. It is installed in the inlet to the first section between the transfer pump and plate heat exchanger. Basically two types of flow controllers are used:

- a) Orifice overflow system
- b) Flow controller based on the dynamic principle (with floating device)

The orifice overflow system (Figure 4./48) is used for separators which have an open inlet into the process line. The principle is that a throttling device in the inlet pipe (orifice) permits the passage of a limited quantity of milk. If this quantity is exceeded, the surplus milk returns via a return line into the feeding vessel. The return line must be installed on a level which is suitable for the orifice.

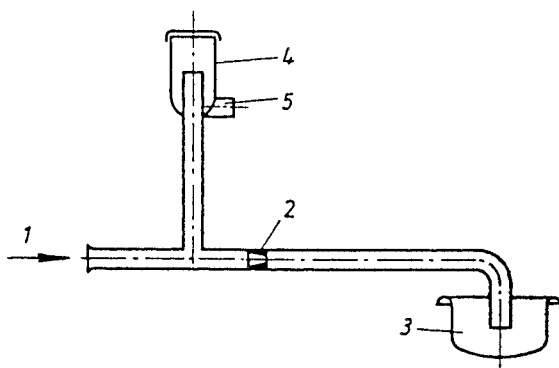


Figure 4./48 Flow controller type MBA 5/0

(1) Inlet (2) Orifice (3) Separator feed vessel (4) Overflow vessel (5) return line

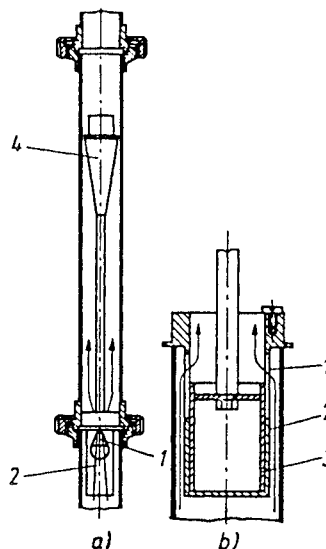


Figure 4./49 Flow controller type MB 5/1

(a) Total view (b) Detail

(1) Pear-shaped opening (2) Liner with closed bottom (3) Control rod (4) Floating device

Flow controllers with floating devices, which can adhere better to the tolerance limits, are used for separators with a closed infeed. The flow controller in Figure 4./49 shows the milk flow (see arrows), which pass the liner (2) with a closed bottom and then enters the pear-shaped orifice (1). The milk then flows upward in the direction of the floating device (4), which is lifted due to the buoyancy and thus pulls the control rod. The control rod modifies the pear-shaped opening, which changes the flow rate. The flow control depends on the buoyancy of the floating device and the throttling of the milk flow by the floating device.

4.2.8. Cooling of milk

Cooling is done immediately after the heating process. This reduces the thermal risks for the milk, and the temperatures are reduced below the heating temperatures.

The final temperatures are selected as a function of the foreseen utilization of the cooled milk. Milk which is processed immediately thereafter can be kept at 10–25 °C. Fresh milk and milk mix drinks require cooling to < 6 °C. This prevents or reduces significantly growth of possible recontamination microorganisms, preserving the milk.

Operation. Milk cooling is done mostly in several stages. It begins with a heat exchange with the non-heat-treated milk, in order to recover part of the energy. Then fresh water cooling is done, followed by ice water (chilled artificially to 0 °C), and finished with brine (a salt solution) or other refrigerants.

Milk coolers can be differentiated between open and closed designs. Open coolers are either spray coolers or tube evaporation coolers, where the milk flows over sequentially arranged tubes containing the refrigeration medium. With these types the warm milk can be easily deaerated, thus eliminating feeding influences; however, an acute recontamination risk is posed by environmental air. The economics of this type of heat transfer are not advantageous.

Closed coolers use plate heat exchangers, whose principles have already been described. Sometimes tube coolers are used, where the milk passes through a tubular system, with the chilling medium on the outside.

The cooling medium and the milk nearly always flow in a countercurrent system; a setup with the same flow direction is very rare.

- When using brine or cooling media with temperatures < 0 °C, the flow of the cooling medium must be stopped before the milk flow is interrupted, in order to avoid freezing of the installation.

Apart from the hygienic advantages, closed coolers have also energy advantages; therefore they are most widely used in milk chilling.

4.3. Process lines

4.3.1. Milk processing lines

4.3.1.1. Equipment and capacity

Equipment and capacity of the milk processing lines are mainly influenced by the following criteria:

- a) Technological objectives, i.e., with or without cream heating, bactofugation, homogenization etc.
- b) Quantity to be processed daily
- c) Design and capacity of the machines and installations
- d) Utilization (shift utilization) of the process lines

The process lines have defined capacities (given as flow rates per hour, erroneously given as performance) which are based on the heat exchangers. All other machines and installations are adjusted (with regard to capacity and numbers) to the heat exchangers. Flow rates are generally standardized and have values of 1250, 3000, 5000, 10,000, 12,500, 20,000, 25,000 or 30,000 l/h. Cream processing lines (heating, deaeration) can be attached to the milk processing lines, and their capacity is in line with that of the milk processing lines.

Generally, the departments are designed to accommodate the installation of two processing lines. In case of an interruption on one line, milk processing can be completed on the other line on the same day. If non-self-cleaning centrifuges are used, a third de creaming separator is needed for two processing lines, in order to switch over to the third machine during desludging and thus continue with the milk processing.

4.3.1.2. Technology

The process line as shown in Figure 4./50 has a flow rate of 20,000 l/h. Raw milk is transferred with a centrifugal pump from the storage silo via a drum sieve into the feed vessel (1), where the fluid level is controlled by a floating device. The pumping capacity is set not to exceed a pressure of 3 bar. Another centrifugal pump transfers the milk via a flow controller (3) into section 1 of the plate heat exchanger. The return flow of the heated milk preheats the incoming milk to the decreaming temperature and it is then transferred to the separator (6). After clarification and decreaming, the separated skim milk and cream can be recombined immediately after leaving the separator, if the milk must be kept at its original fat level. If the fat level must be standardized, these fluids pass through a standardization installation. Otherwise, the fluids are pumped separately and are treated further in the process lines.

In the separator a pressure of $p_{max} = 5$ bar is created, and the milk passes through the section II of the heat exchanger, where it is further heated up by the return flow of the holding section (5). The milk has now reached a temperature of 65 °C and enters the heating section III. Here it is heated further to the preset temperature. Heat is added by using hot water, which is circulated through a mixing battery (9) with a centrifugal pump (7). The target temperature is set in the temperature control unit (11) (see 4.3.1.2) and is kept within the predefined limits.

After leaving the heating section, the milk is transferred with a pump (not shown in the figure) into the tubular holding section (5). Due to the induced pressure drop, the pressure in the heat exchange sections is now higher than at the inlet. In case of a leak, e.g., due to corroded plates, this prevents mixing of nonpasteurized milk from the inflow with the heated milk in the outflow. The leak flow always goes in direction of the non-heated milk. The pressure difference between outflow and inflow is 1.05–4.5 bar. A suitably set valve maintains a constant overpressure. The actual pressure is determined and recorded. The pump for increasing the pressure can also be installed after the holding section.

A switching valve (8) is installed between heating and holding sections. If the milk has not reached the required temperature after passing through the heating section (which is determined with the thermometer, 12), then the flow patterns are modified by the switching valve in such a way that the milk returns into the feed vessel (1). In such a case, the entire installation must be cleaned and must be restarted. Cleaning is not necessary when the temperatures have been exceeded slightly due to switching. The switching valve can also be installed after the holding section.

After passing the holding section, the milk returns to heat exchange sections II and I, thereafter goes through chilling section IV and leaves the installation with a temperature of 5 °C. Heat recovery in the exchange sections is about 80–92%.

Cleaning of the process line. Cleaning of the milk processing line is done with a CIP installation, as is described in section 11.5. The multidirection valve (19)—installed at the milk outlet of the plate heat exchanger—is set in such a way that the cleaning solution returns to the feed vessel. If the separator is included in the cleaning circuit, then the cleaning fluid should have a temperature of 30 °C, which is raised 15–20 min later to a level of 71–74 °C or another specifically chosen temperature. This avoids the coagulation of the protein, which still can be inside the separator, and a reduction of the cleaning effect.

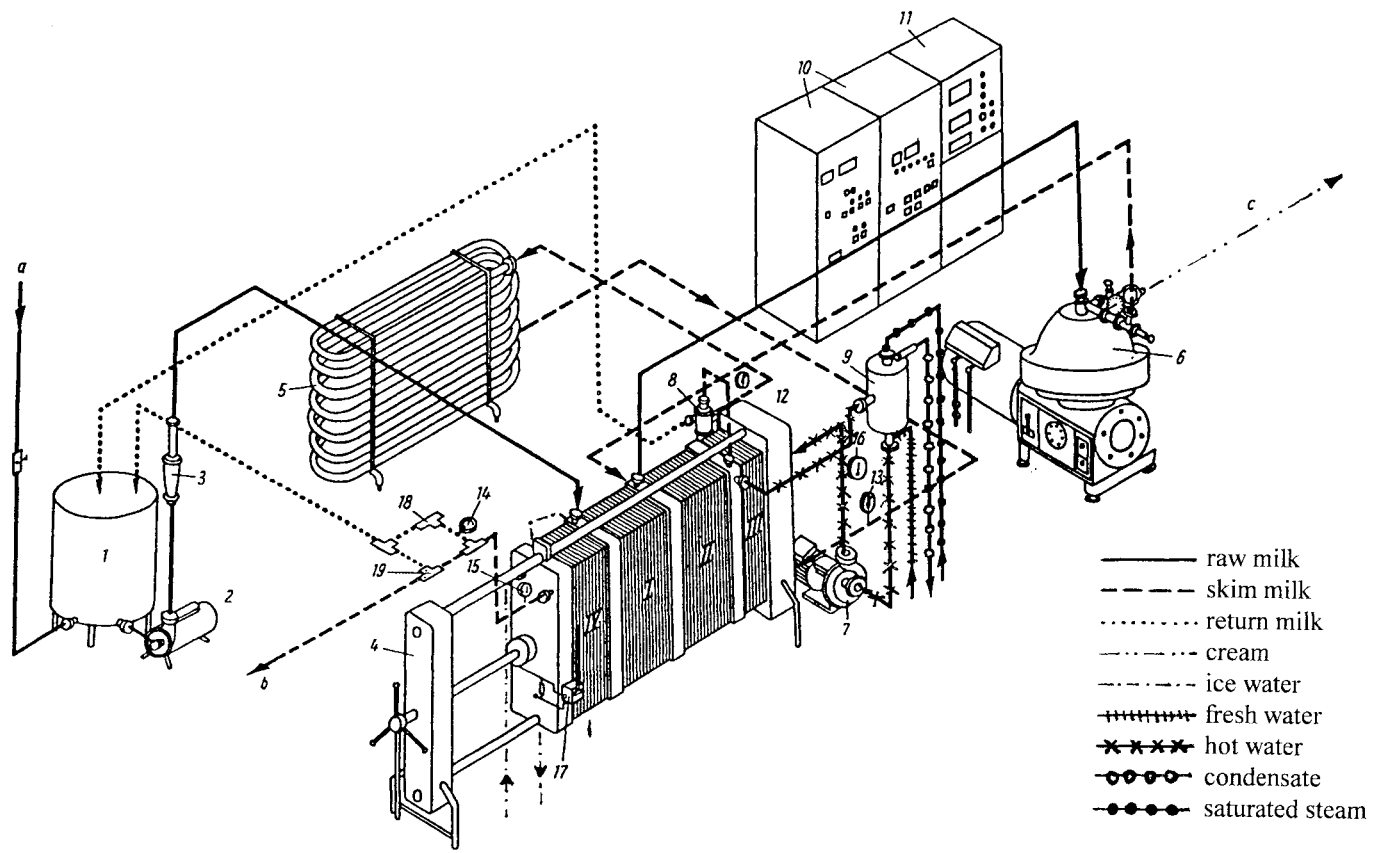


Figure 4./50 Process line for milk treatment. Flow rate 20,000 l/h

a) Raw milk inlet b) Skim milk outlet c) Cream outlet

- (1) Buffer tank with floating device (2) Centrifugal pump (3) Flow controller (4) Plate heat exchanger (I, section 1; II, section 2; III, holding section; IV, ice water chiller) (5) Tubular holding section (6) Self-cleaning separator (7) Hot water pump (8) Switching valve (9) Hot water mixing battery (10) Separator control panel (11) Control panel (12) Thermometer for control panel (13) Thermometer for temperature recorder (14) Pressure gauge (15) Milk outlet thermometer (16) Hot water thermometer (17) Hydraulic tightening device (18) Three-way valve (19) Three-way valve

4.3.1.3. Flow control installations

The inclusion of such installations in the process line meets a hygienic requirement for heat exchange plants. The temperature control units serves for the following purposes:

- a) Control of the heating temperatures
- b) Recording and indication of the heating temperatures
- c) Visualization and recording of the flow

Design and operation. The plant, as shown in Figure 4./51, works on electro-pneumatic principles. It has two basic circuits, the first is for controlling the temperature, and the second is for actuating the valves with temperature recording and visualization of the flow.

Temperature control. The temperature is determined with a sensor (21), which is installed immediately after the milk outlet of the heating section and is totally immersed in milk. The controller (12) compares the actual voltage (actual temperature) with the target voltage (target temperature). The target value X_K and the transfer factor X_p can be set on the controller. Lag time t_N and lead time t_V can be set in the timing unit (13).

In case of temperature deviations, the target value is controlled by addressing the initial voltage of the controller to a system converter (15), which converts a uniform voltage (−10 to +10 V) into a proportional air pressure of 0.2–1.0 bar. The control voltage creates a magnetic field, moving a plate in front of an air nozzle (Figure 4./52). According to the degree of opening the nozzle, the increasing air pressure effects the valve (17) (via the system converter) and modifies the steam flow by its actuation.

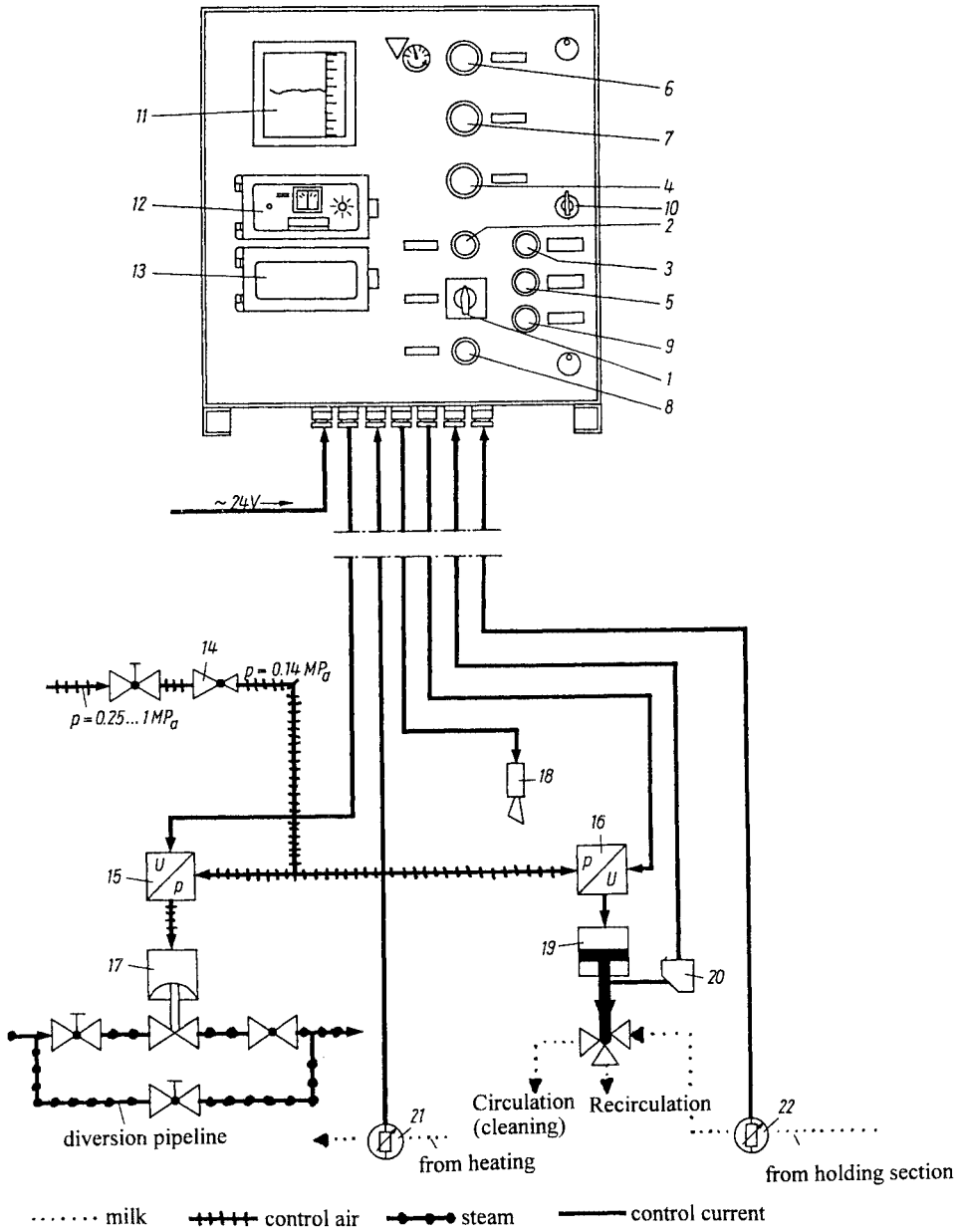
The control valve (Figure 4./53) works in such a way, that when the shaft moves downward, actuated by the air pressure on the membrane, the orifice opens. If the set value is equal to the actual value due to the increased inflow of the heating medium, then the steam flow is reduced; the plate is slightly lifted, and air escapes through the nozzle. The air pressure of the valve membrane is reduced, and the valve is closed with a spring.

Switching installation with temperature recording. The principle is identical to that of a control unit; the temperature sensor for short-time plants is installed after the heating section. The measured voltage—identical to the one in the control unit—actuates a recording device (11), which indicates and records the actual temperature of the medium from beginning to end of the operating period as well as the status of the switching valve (for “passage,” “circulation” and “cleaning”). Recording is done with a dot printer on recording paper (Figure 4./54). At the same time the actual recording time can be read from the recording paper.

If the temperature falls below the set temperature, the recorder emits a signal, which actuates the mode “circulation.” For this an electrical impulse from the magnetic valve

Figure 4./51 Temperatue control and flow-regulating installation for a milk heat treatment plant

(1) Main switch (2) Voltage control (3) Key button (4) Signal lamp white “cleaning: (5) Signal button “cleaning-circulation, automatic mode” (6) Signal lamp red “circulation” (7) Signal lamp green “recirculation” (8) Signal button “alarm reset” (9) Signal button “recirculation” (10) Safety switch (11) Recorder (12) Electropneumatic controller (13) timer (14) Auxiliary air control valve (reducing valve) (15) Signal converter (16) Signal converter (17) Regulating valve (18) Signal horn (19) Switching valve (20) Signal switching transmitter (21) Temperature sensor (platinum resistance thermometer) (22) Temperature sensor (platinum resistance thermometer)



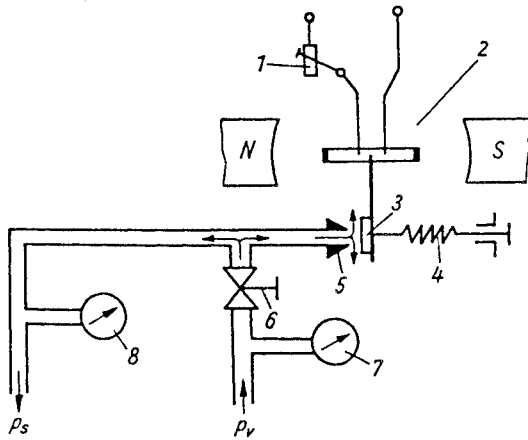


Figure 4./52 Principle of a system converter for the conversion from electrical to pneumatic signals

p_V initial pressure (1.40 bar, +0.10 bar, -0.20 bar)
 p_S set pressure on control valve (0.2–1.00 bar)
 (1) Initial resistance (>4 k Ω) (2) Magnetic field (3) Plate (4) Spring for counterpressure onto the plate (5) Air nozzle (6) Throttling valve (7) Initial pressure gauge (8) Set pressure gauge

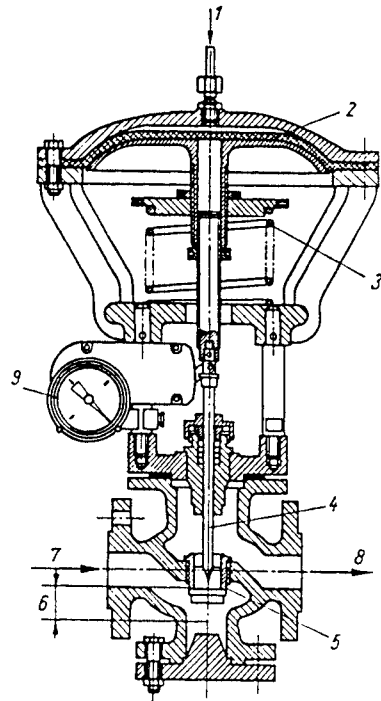


Figure 4./53 Membrane control valve

(1) Control air inlet (2) Membrane (3) Spring (4) Valve shaft (5) Valve seat (6) Valve displacement (7) Steam inlet (8) Steam outlet (9) Indicator and transmission

(16) is converted into a pneumatic signal, control air escapes from the compressed air pipeline, and valve (19) (see also Figure 4./55) is moved into position “circulation” with the help of a spring. This mode remains until the cause of the disruption has been eliminated.

4.3.2. Ultra-high temperature installations

The acronym UHT (ultra-high temperature) is used mostly when describing plants or process lines for ultra-high temperature treatment. UHT plants are mostly operated in automatic mode; have monitoring, control and recording functions; and consist of three basic process steps:

- a) Presterilization and startup
- b) Manufacturing
- c) Cleaning

In case of need, an additional process step can be added, aseptic intermediate cleaning. UHT installations have a wide array of safety devices, which exclude mixing of sterile with nonsterile product. Plants can be distinguished by very characteristic differences in the heat transfer sections of the UHT sections. We distinguish between direct and indirect processes.

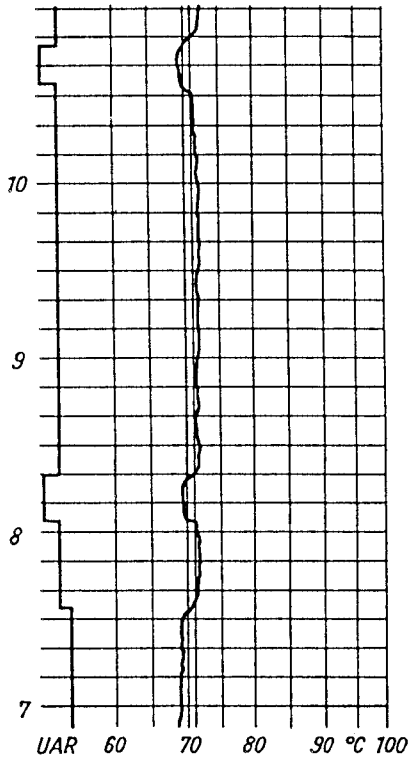


Figure 4./54
Diagram of the temperature recorder

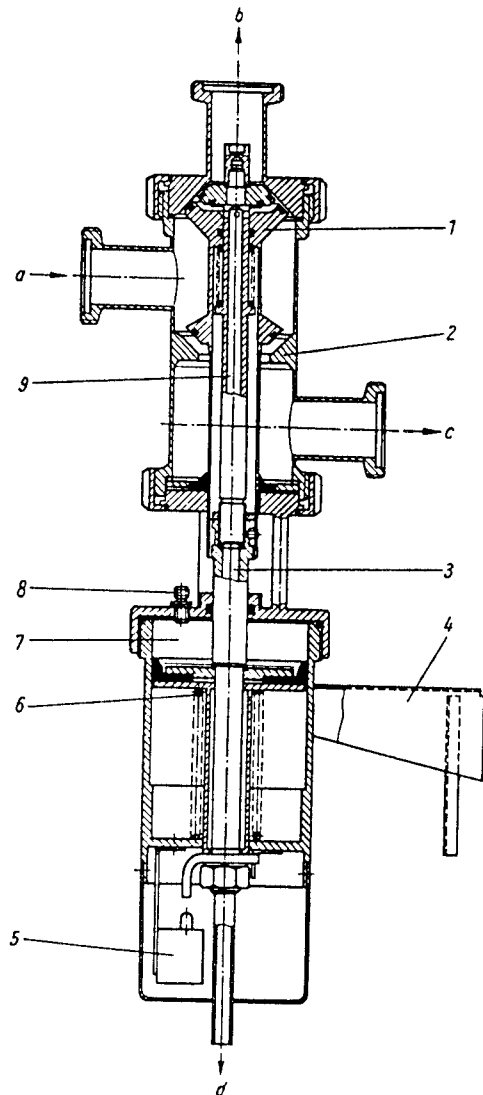


Figure 4./55

Switching valve, type UV 40/1

a) Milk inlet from holding section b) Passage to exchanger section II (return) c) Circulation to feed vessel d) Outlet for leaking milk

(1) Valve seat (2) Valve housing (3) Hollow shaft (4) Support (5) Switch (6) Spring (7) Cylinder headspace (8) Compressed air connection (9) Hollow shaft for deviation of leaking milk

Direct UHT process. Milk is blended directly with steam in the heating section by either steam injection into milk or milk injection into steam. Preheating and cooling are done indirectly in plate or tubular heat exchangers. The heating temperatures are in the range 140–150 °C with a heating time of < 1 s. Water which has been added to the milk is removed by subsequent expansion in a well-defined vacuum, thus obtaining the initial

milk composition. At the same, energy is removed by the expansion and the milk temperature is reduced well below the critical temperature range. The advantage of this is an extremely short heating time of 0.5–1.0 s and subsequent mild product treatment. Disadvantages are the high quality requirements for steam (“culinary steam”) and a low level of heat recovery (only 40–50%).

Design and principle of a process line are shown in Figure 4./56. Milk is pumped from a storage silo into a buffer tank (1). From there it is transferred by a centrifugal pump (2) into a plate heat exchanger (3) and is heated to 75 °C with hot water. The water used for preheating the milk is heated by condensate from the vacuum vessel (8) and is brought up to temperature by adding fresh steam with a steam injector (4). The steam quantity is controlled by a temperature controller in such a way that the milk leaves the plate heat exchanger with a constant temperature of 75 °C.

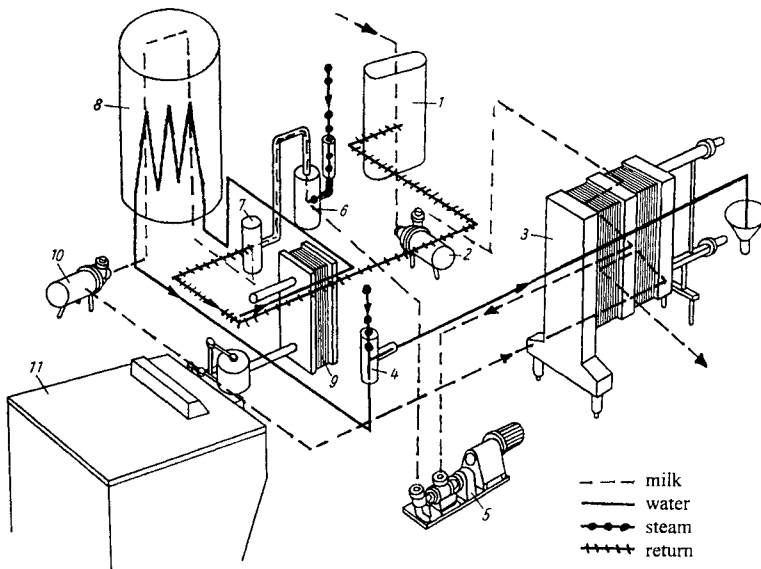


Figure 4./56 Ultra-high heat installation with direct heating type VTI

(1) Buffer tank with floating device (2) Centrifugal pump (3) Plate heat exchanger (4) Steam injection preheater (5) High-pressure pump (6) Steam injection (7) Switching valve (8) Vacuum tank (9) Return flow plate heat exchanger (10) Aseptic centrifugal pump (11) Aseptic homogenizer

A high-pressure pump (5) transfers the preheated milk to the steam injector (6), where the temperature is raised to 140 °C by injecting saturated steam. This temperature is maintained for 3–6 s in the holding tube, and then the milk reaches the vacuum vessel (8) after passing through a switching valve (7), where a constant vacuum is maintained. Here the milk is cooled to 76 °C by expansion, and exactly the same quantity of water is removed which has been added previously by steam injection. The dry matter content of the milk is exactly maintained with a special control device. Condensation of the evaporated water takes place in a spiral condenser, which is integrated into the vacuum vessel.

Sterile milk is then transferred with an aseptic centrifugal pump (10) from the vacuum vessel to the aseptic homogenizer (11), where it is treated with 250–300 bar. Then it is pumped to the aseptic cooler (3), where it is cooled down to 20 °C with cooling water from the preheating section. This water circulates between return flow cooler, condenser, preheater and aseptic cooler with considerable heat recovery. From the aseptic cooler, the

UHT product is then pumped into the sterile tank (Figure 4./58) or straight into a filling machine(s).

Switching devices. If the UHT temperature after the steam injector (6) falls below the set temperature, then switching valve (7) is actuated, which diverts the milk to a plate heat exchanger, cooling down the milk to 75 °C, and then transfers it to a storage tank. This prevents insufficiently heated milk passing into the aseptic part of the plant and causing a recontamination. As soon as the switching valve is actuated, the product pump (10) and homogenizer (11) are stopped. Further, the milk supply is stopped, and the plant changes over to sterile water circulation. Once the circulating water has reached the UHT temperature of 140 °C, production can be restarted after a delay of 2–3 min without pre-sterilizing the plant again.

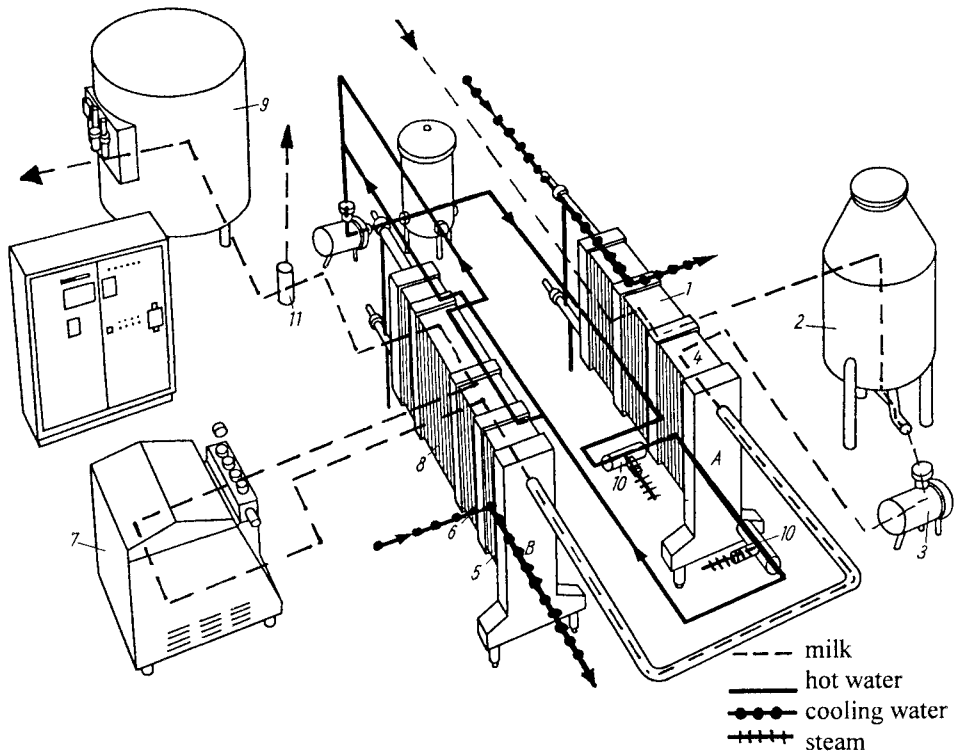


Figure 4./57 Ultra-high temperature plant with indirect heating type VSA/T

(1) Plate heat exchanger section A (2) Vacuum tank (3) Pump (4) Plate heat exchanger section A (5) Plate heat exchanger section B (6) Plate heat exchanger section B (7) Aseptic homogenizer (8) Plate heat exchanger section B (9) Sterile tank (10) Steam injector (11) Switching valve

Indirect UHT process. The entire heat transfer, including the UHT stage, takes place in a plate heat exchangers, tubular heat exchangers or a combination of both types. For the UHT section proper, tubular heat exchangers are more advantageous. Due to their geometry, fluid velocities of 2.5 m/s at pressure levels of 40–60 bar are possible, which resulting in very short heating times and therefore reduced residence times. Using plate heat exchangers in the UHT section means using a lower pressure (due to their geome-

try) and more complicated sealing requirements, which result in fluid velocities of 0.25–0.35 m/s. The advantage of indirect heating is high energy recovery (heat recovery) of 88–90%, leading to significantly improved economies. The disadvantage of the higher thermal product degradation has been minimized constantly, so this approach is applied often in reality because of the economic advantages.

Design and operation of a process line with indirect heat transfer are shown in Figure 4./57. Before start-up of production, the plant is personalized like all other UHT plants. For this, water at 140 °C, which has been heated up with hot water and steam, circulates through the aseptic part of the plant. After a treatment of some 30 minutes, the plant temperature is reduced to the operating temperature and production can commence.

Milk is transferred with a centrifugal pump from the buffer tank to the plate heat exchanger (1) and is preheated with water to a temperature of 77 °C. Deaeration of the milk takes place in the vacuum vessel (2) with simultaneous cooling by expansion to 70 °C. The condenser, integrated in the vacuum vessel, immediately condenses the evaporated water and adds it back to the product, whereas the noncondensable gases and odors are removed by the vacuum pump. This plant can also be operated without vacuum deaeration. Milk is then transferred with a pump (3) to the UHT section of the plate heat exchanger (4), where the product temperature is raised to 140 °C in a countercurrent flow, and the product is kept at this level for 3–4 sec. In the first cooler (5) the milk temperature is reduced to 105 °C (by using water), and is then reduced further to 76 °C in cooler (6). At this temperature, the milk enters the aseptic homogenizer (7), is further cooled to 20 °C and is filled into a sterile tank (9). In case of interruptions in the plant or UHT temperature deviations, the control unit switches valve (11) to the circulation mode, and the milk flows into an intermediate storage vessel. At the same time, the milk supply is stopped, and water for another Presterilization is pumped into the feed vessel.

The total treatment times for the products are very different from plant type to plant; they range between 20 and 120 s, but can also reach 400–450 s. All plant sections (e.g., pumps, homogenizer) which are in contact with the product in the UHT section are designed for aseptic operation; i.e., the transfer or treatment areas are sealed by steam. This steam seal excludes microbiological contamination. The capacity of UHT process lines usually ranges from 1000 to 12,000 l/h. Sterile tanks serve as buffers between the UHT plant and the aseptic filling lines.

Design and operation of a sterile tank (Figure 4./58). The design calls for either a vertical or horizontal construction, and the insulated sterile (or aseptic) double-walled tank is presterilized for about 45 min at 135 °C; the same process is applied to the pipelines going into and out of the tank. The next operation is a water cooling of the double-walled tank, and sterile air is injected into the tank to remove the condensate from it. Once the tank has reached 20 °C, product can be filled into it.

Compressed air, which has passed two sterile air filters (20 and 21) enters the tank. In order to maintain a constant pressure in the tank, an air pressure sensor (11) has been installed, which transmits the data to a control unit (12), which then actuates the control valves (9) and (10). These valves control the air flow and the air pressure inside the tank. Pressure in the product pipeline is controlled by the sensor (14) and the controllers (15) and (16).

During discharge and storage of the product, connection valves (V) and (VI) are protected by steam seals from the outside. The pipeline system can be set up for a direct connection between the UHT plant and the filling installation, and then valves (I), (V) and (VI) are activated and valves (VII) and (VIII) are protected by a steam seal.

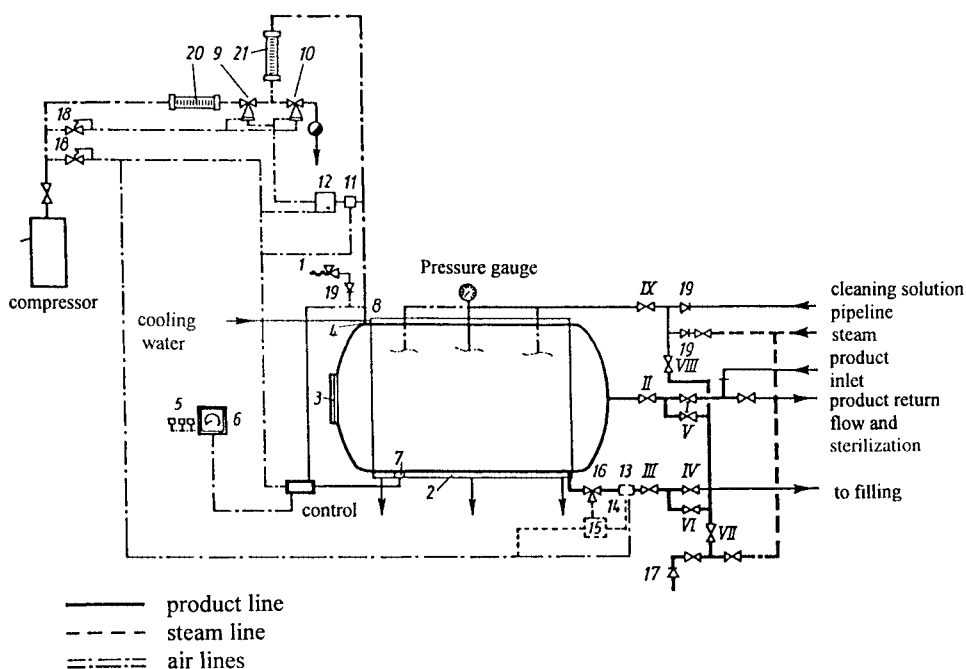


Figure 4.5/58 Flowsheet for a sterile tank with auxiliary installations

(1) Safety valve (2) Double wall (3) Manhole (4) Compressed air connection (5) Signal lights (6) Pneumatic level indicator (7) Pressure converter (8) Connection sterile air (for level indicator) (9) Control valve (10) Control valve (11) Pressure sensor (12) Pressure controller (13) Pressure converter (14) Pressure sensor (15) Pressure controller (16) Control valve (17) Condensate discharge (18) Reducing valve (19) Check valve (20) Sterile filter (21) Sterile filter (I) to (IX) Membrane valves

4.4. Dairy equipment

Basic knowledge for a dairy technologist includes information about auxiliary materials, such as

- Machines, instruments and installations (including pipelines for the production of milk), transport, treatment and storage of milk and dairy products.

The following criteria must be considered:

- a) Material usage; above all inertness (no reaction with the products) and a corrosion resistance are required
- b) Surface characteristics; they must permit efficient cleaning and impeccable hygiene
- c) Shape and functionality; they guarantee efficient layout of the operating elements, workplace safety, safety for electrical installations, and quality-oriented and efficient manufacture of products

In dairy technology auxiliary elements are assembled into modules and connected mostly by pipelines. Monitoring and controlling are done by instruments, pumps are used for material transport, and stirrers are used for mixing. Symbols are used to depict

these auxiliary installations in flowsheets, drawings or technical descriptions, which facilitates comprehension of these technical documents, when they are applied uniformly.

4.4.1. Equipment, machines, vessels

4.4.1.1. Equipment and machines

Machines and equipment together with connecting and transferring installations (pipelines, instruments, pumps) are elements of process lines or installations and serve for processing in a suitably adjusted manner.

- Machines are installations consisting of mechanical elements, having a base frame (base, stand, housing), a moving part and a drive.

According to their function, we distinguish between power installations (supplying or transforming motor force or energy) and working installations (e.g., separators, pumps, homogenizers, filling installations, packing lines).

- Equipment consists of installations, mostly without movable parts, which serve in process operations (e.g., heat exchangers, filters, evaporators, retorts).

4.4.1.2. Vessels

Another component of production installations is vessels.

- Vessels are installations which serve in the reception of the material (raw material, intermediate and finished product)

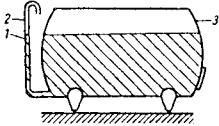
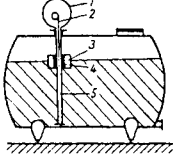
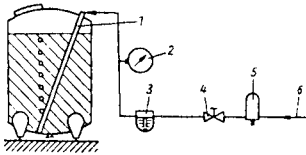
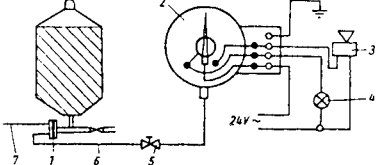
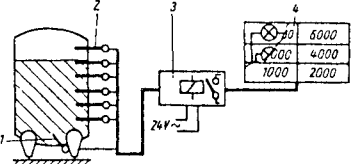
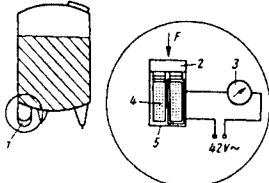
In dairies numerous different vessels can be encountered. According to the type and utilization, we distinguish between open vessels and closed vessels (tanks, silo), the latter in a fixed design (storage silo) or a movable transport tank. According to the type of utilization, these vessels can have a double wall; therefore they can be temperature controlled (cheese tank, cream tank, tempering vessel), can be closed hermetically (sterile tank) or can have an insulating layer. Silos are mostly noninsulated and with a single wall (see 4.3.1). For mixing, stirrers with a special design (see 4.4.5) are used.

As a material, mostly stainless steel is used, apart from compounds like steel-glass-enamel, aluminum (purity 99.5%) and fiberglass-reinforced thermoplastics. The capacity of vessels in dairies ranges from <100 l for tempering vessels to >200,000 l for silos.

For production monitoring, level control is necessary, and for this purpose silo level controllers, sometimes with semiautomatic data transmission and recording devices, are used. The main types are described in Overview 4./5. A milk tank with a horizontal design is shown in Figure 4./65, and the required information is shown in Overview 4./6.

- The manhole or tank cover must have a facility, which prevents the closing of the tank during a manual cleaning.

Overview 4./5 (Figures 4.59 to 4./64) Tank measuring devices

Indicator type	Construction	Principle
Figure 4./59 Side glass		<p>An open-top heat-resistant glass tube (2) is connected to the tank (3) and the system of communicating tubes is applied. The corresponding tank volume can be read on the notches (1) of the glass tube.</p>
Figure 4./60 Floating device indicator		<p>A floating device with an annular magnet (3) moves with every change in the liquid level. The permanent magnet (4) is guided by a tube (5) and is connected to a chain (2).</p>
Figure 4./61 Head space pressure device		<p>An immersed tube (1) with a bottom opening is connected to a pressure gauge (2). This gauge is supplied with compressed air (6) via a filter (5), a regulator valve (4) and a control side glass (3). The air pressure is slightly higher than the liquid pressure, resulting in a continuous discharge of air at the bottom of the tank from the tube. The liquid in the tank creates a counterpressure to the air pressure in the tube, which changes as a function of the liquid level, which is shown by a pressure gauge.</p>
Figure 4./62 Static pressure device		<p>Compressed air is fed to the pressure sensor via a pipe (7), located at the outlet of the tank. The liquid pressure modifies the air pressure correspondingly, resulting in a pressure to the gauge (2) via the air pipe and a valve. With electric sensors and contacts, the levels "full" and "empty" can be read from optical and acoustic (3) signals.</p>
Figure 4./63 Electrode level control		<p>A sensor is installed at the bottom of the tank and is connected to other sensors (2). By using the electrical conductivity of milk, circuits are closed as a function of the liquid level, made visible by a circuit control (3) on a panel (4). This indicated the level.</p>
Figure 4./64 Load cells		<p>One (1) of the three feet of the tank is used for weighing. The filled tank reacts as a force F (a function of the weight on a steel plate (2), which changes the air gap in an electrical coil. This changes the inductivity of the coil and therefore the resistance to the alternate current. The change in the flow of current is indicated and is converted into volume (based on previous calibrations).</p>

Overview 4./6 Milk storage tank (Figure 4./65)

Equipment item	Purpose	Remarks
Tank space (1)	Reception of the product	Net volume 6300 l
Feet (2)	Support of the tank	Level control with adjustable feet
Discharge outlet (3)	Discharge of product	
Outer shell (4)	Protection of the exterior	Material: enameled steel, stainless steel, aluminum, plastic
Inner shell (5)	Enclosure of product	Material: stainless steel, aluminum, enameled steel, plastic-coated fiberglass laminate
Insulating layer (6)	Protection against temperature variations	Between inner and outer shell, thickness 50 mm
Manhole with cover (7)	Access for manual cleaning	Lid can be closed tightly; when the lid is opened, a proximity switch stops the stirrer
Thermometer (8)	Temperature indicator	
Inlet pipe (9)	Inlet of product	Directed toward the inner shell to avoid foaming
Sampling cock (10)	For sampling purposes	
Motor for stirrer (11)	Mixing of product	Slow-moving stirrer (200 RPM) permits gentle mixing of the product;
Connection for level control (12)	Installation of measuring device	see Overview 4./5
Dehumidification device (13)	Dehumidification of insulation layer	Filled with hygroscopic material (e.g., Kieselguhr)
Spray nozzles (14)	For CIP	

4.4.2. Materials and surface characteristics

Materials can be differentiated into types which are in contact or not in contact with the product.

- Materials in contact with the product must be nontoxic, and should be inert to foods or should not influence foods negatively.
- Materials not in contact with food have to comply with the special requirements of a dairy, i.e., must be solid, stable and corrosion proof.

Natural materials such as wood is used only rarely. Overview 4./7. shows the major technical materials used in dairies. To a very large extent, stainless steels of different qualities are used, such as rust- and corrosion-proof alloys, e.g., chromium-nickel steels (CrNi-steel), as well as stainless steels (German term "Nirosta" or V2A steel). The materials differ in their content of carbon, chromium, nickel, titanium, and molybdenum as well as their chlorine resistance and welding characteristics.

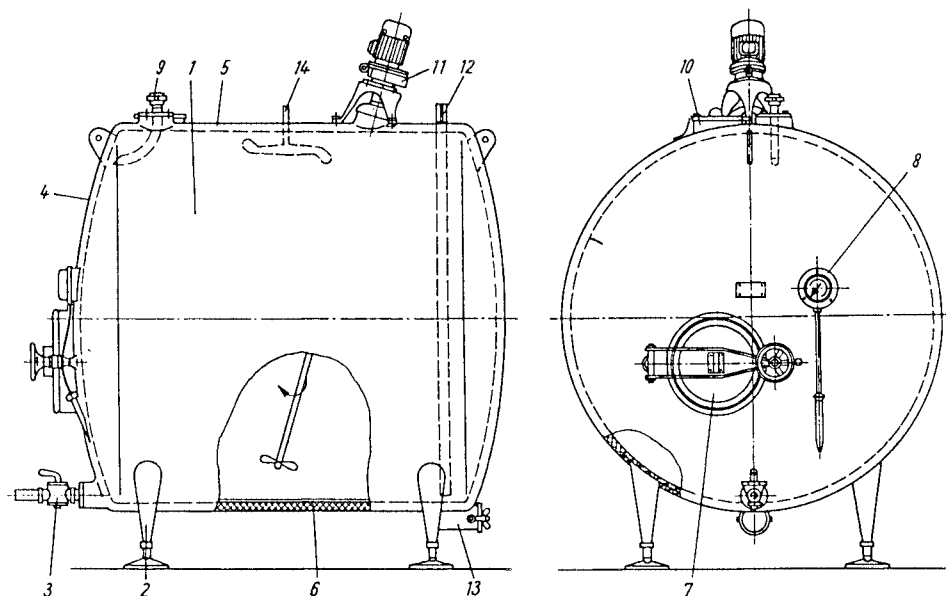


Figure 4/65 Milk storage tanks

(1) Filling volume (2) Cone legs (3) Discharge valve (4) Outer shell (5) Inner shell (6) Insulating layer (7) Manhole with lid (8) Thermometer (9) Inlet pipe (10) Sampling cock (11) Motor for stirrer (12) Connecting piece for level control (13) Dehumidification cavity (14) Rotary spray nozzle for chemical cleaning

Surface characteristics. The surface characteristics of dairy materials have a considerable influence on the type of cleaning and adherence to hygienic norms. The requirements are influenced by product contact, visual control possibility (e.g., silo surface) or whether the equipment must be dismantled for control (e.g., inside of tubes).

- Surfaces in contact with the product must be well ground, polished electrolytically or mechanically, or must be cold rolled.
- Surfaces not in contact with the product must have a uniform appearance, well polished to a high gloss or matte finish, well ground, steeped in corrosive liquid, or lacquered or treated in a similar way.

The surface characteristic is expressed as coarseness and indicated by a micrometer. For visually controlled surfaces, the average coarseness R_Z (average distance between the five highest and five lowest peaks of a profile within the reference distance) should be $\leq 10 \mu\text{m}$, individual results can be $\leq 15 \mu\text{m}$ and the average coarseness R_A (arithmetic average of the absolute height and bottom of the actual profile versus the target profile) should have an average of $\leq 2 \mu\text{m}$ (individual data $2.5 \mu\text{m}$). Technological exceptions can be found in the kneading helixes of a buttering machine, parts of the butter forming machine and others.

For visually uncontrollable areas we should maintain $R_Z \leq 1.0 \mu\text{m}$, $R_A \leq 0.2 \mu\text{m}$ and a coarseness depth (maximum distance of the base profile from the reference profile) R_T

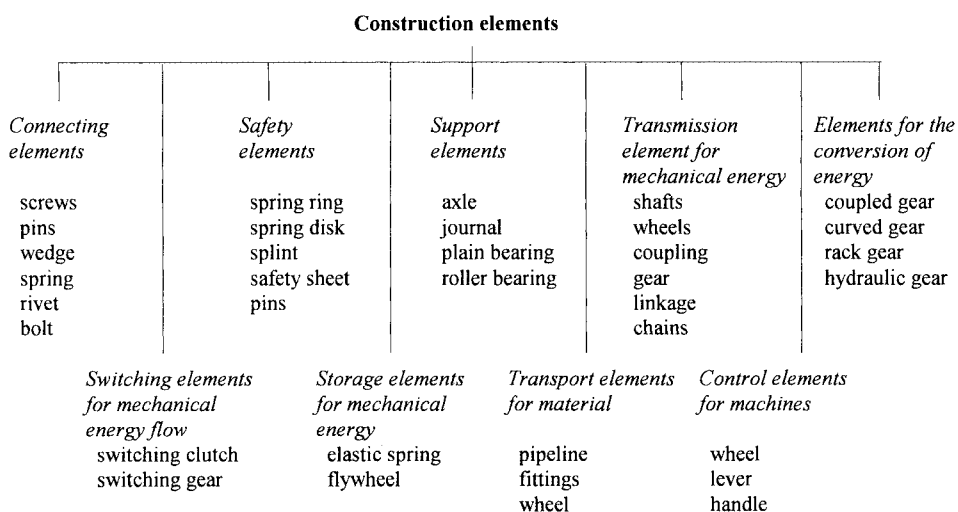
≤1.3 μm. These data are not valid for instruments and welding connections of pipes and instruments. The welding joints should be smooth, free of lumps and discoloration.

4.4.3. Construction elements

- Construction elements are individual or several jointly operating parts of machines, equipment and instruments.

The functional design and utilization of construction elements, as well as their material and durability, have a significant influence on the quality of the dairy material. a possible classification of these construction elements is shown in overview 4./8.

Overview 4./8 Classification of construction elements¹



¹ According. to Hintze, J.: Maschinenelemente, Baugruppen und ihre Montage, 15th ed. Berlin: VEB Verlag Technik, 1982.

4.4.3.1. Pipelines

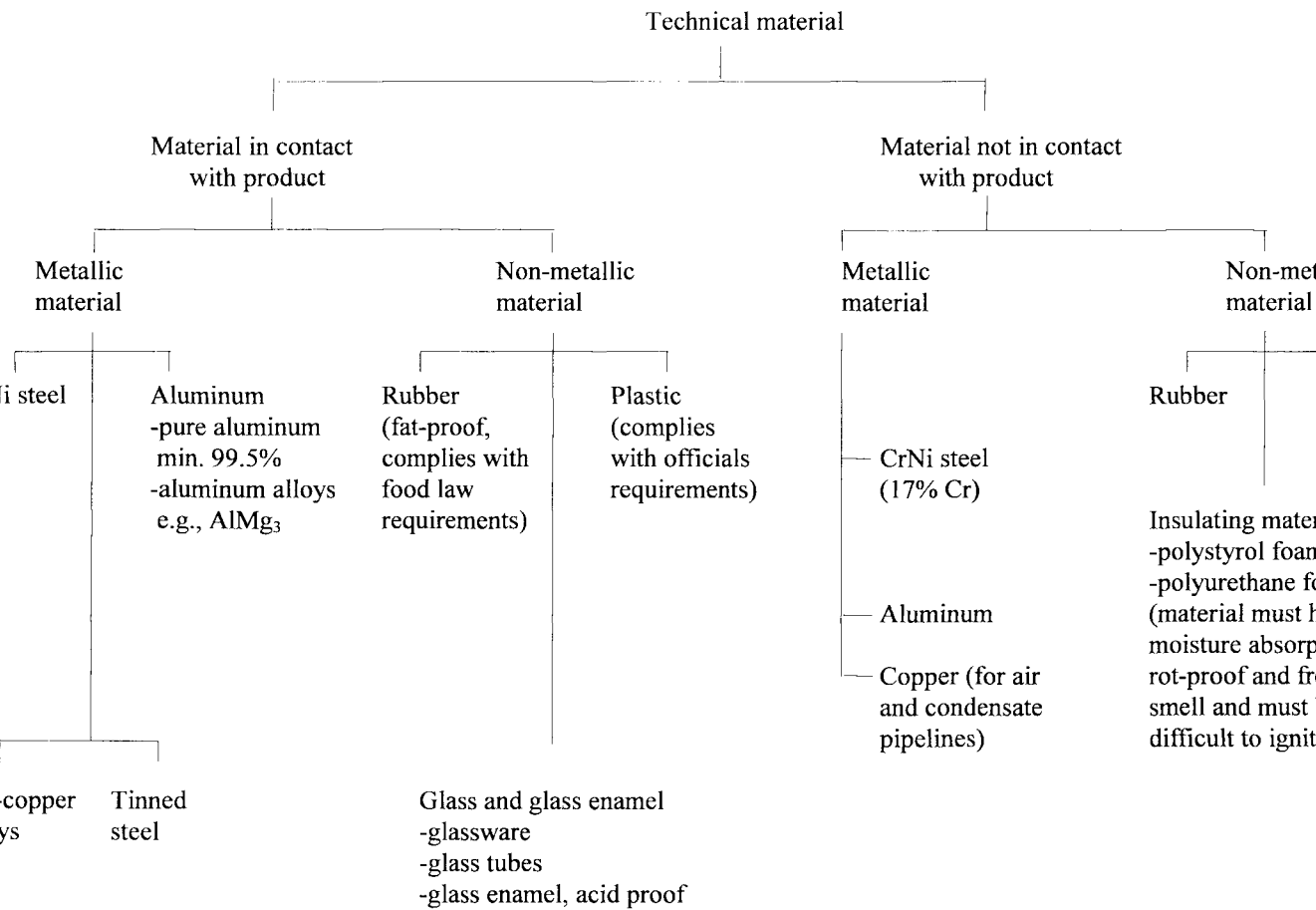
- Pipelines are elements for transport of liquids, viscous products, solids and gases.

The following criteria are important for the selection and project design of pipelines in dairies:

- Suitable material
- Proper dimensioning (diameter, flow conditions)
- Suitable configuration, layout and execution with regard to cleaning and disinfection or hygiene (avoiding dead ends)
- Efficient execution, selection of the most optimal implementation, utilization of welding joints instead of screw connections

Pipelines can be distinguished according to the type of product transported, e.g., for milk, cream, curd, quarg, butter, milk powder and others, and the medium they supply such as water, refrigeration medium, steam, air, lubricant, cleaning and disinfection solutions. The material and the dimensions are chosen as a function of their utilization.

Review 4./7 Materials for dairy equipment



Material. For product pipelines only stainless steel with a surface quality as described in 4.4.2 is used. In certain special cases, glass and plastic, e.g., polyethylene are used. For auxiliary supply lines the same type of material as used for product pipelines is used or materials such as those from Overview 4./7 are used for noncontact parts.

Dimensioning. Flux and fluid velocity v (which is most suitable for the product) are of major importance for the dimensioning of the pipeline. Flux is normally defined by the capacity of the process line and is in the range of 100 to 30,000 l/h. Fluid velocity is controlled by the product characteristics. The following are approximate values:

Raw milk	$v < 1.5$ m/s (risk of buttering the fat)
Skim milk, buttermilk	$v \approx 2$ m/s
Cream	$v < 0.5$ m/s (due to high viscosity)
Steam (saturated)	$v < 30$ m/s
Chilled water	$v \approx 5$ m/s

Pipeline diameters are standardized for the inner diameter (ID). The most common diameters are shown in Figure 4./66, as well as the fluid velocities and flux rates for product pipelines. The average fluid velocity is calculated according to the continuity formula

$$v = \frac{V}{A} = const$$

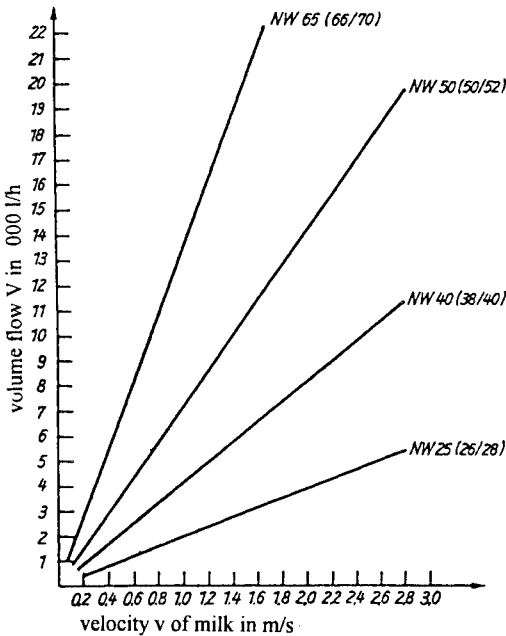


Figure 4./66 Fluid velocities and flux for pipelines made from stainless steel (CrNi-steel)

The data in parentheses show the inner and outer diameters. Apart from the values shown here, there are D32 (32/34), D80 (81/85) and D100 (100/106).

The pipe diameter can then be calculated from the given flux and preset fluid velocity by deriving from the previous equation:

$$d = \sqrt{\frac{\dot{V} \cdot 4}{\pi \cdot v}}$$

\dot{V} flux in m³/h

A area in m²

v fluid velocity in m/s

d diameter in m

Diameter d must be converted to mm in order to use the standardized diameters d_{ID}

4.4.3.2. Fittings

- Fittings are controlling, measuring and closing devices for flowing compounds of all kinds.

Overview 4./9 Connecting elements (Figures 4./67 to 4./71)

Term	Design
Tubular fitting	a) Complete, with rolled end and crown nut (1) Identification location a ₁) Threaded end with rolled end a ₂) Conical end with rolled end b) Complete, with welded end and crown nut b ₁) Threaded end with welded end b ₂) Conical end with welded end c) Nut base d) Crown nut e) Gasket f) Reducing end for welding f ₁) Reducing conical end for welding g) Fitting with orifice (1) Orifice (2) Gasket
Bend (Figure 4./68)	a) One side thread connection, other side conical and with crown nut (1) identification location b) Welding ends on both sides c) One side threaded end, other side with reducing end and crown nut
T-piece (Figure 4./69)	a) Both sides with threaded end (1) identification location b) Both ends for welding c) Deviation with threaded end, passage with conical end and crown nut d) Thermometer 90° angle bend
Check valve	a) Check valve for vertical installation show glass (Figure 4./70) (1) Identification location (2) Closing device (ball) b) Show glass (1) Heat-resistant glass (2) Protective cover
Ceiling passage (Figure 4./71)	a) Thread, protective cover and protective tube b) Without thread, with protective cover and protective tube

Fittings have the same diameters as the pipelines and can be found on the outlets and inlets of equipment, machines and devices or between pipelines, to which they are connected in a fixed or detachable manner.

For detachable connections, fittings are installed on either the thread connection or cone with a crown. A gasket is fitted into the male end. The nut is screwed onto the male end with a spanner. With glass, plastic or steel pipelines, flange connections can be used, with several screws pressing the sealing areas onto each other. Between the sealing areas, gaskets or sealing compounds can be used.

Fixed connections are installed by rolling them into the tube; the tubular area is pressed tight against the profiled area of the male end or the cone, kept tight due to adhesion forces. Another possibility is welding connections (for screwed tubes, tubes, T-pieces and others), where the smooth end of the fitting is welded onto the end of the pipe. Other fixed connections are obtained by gluing and soldering.

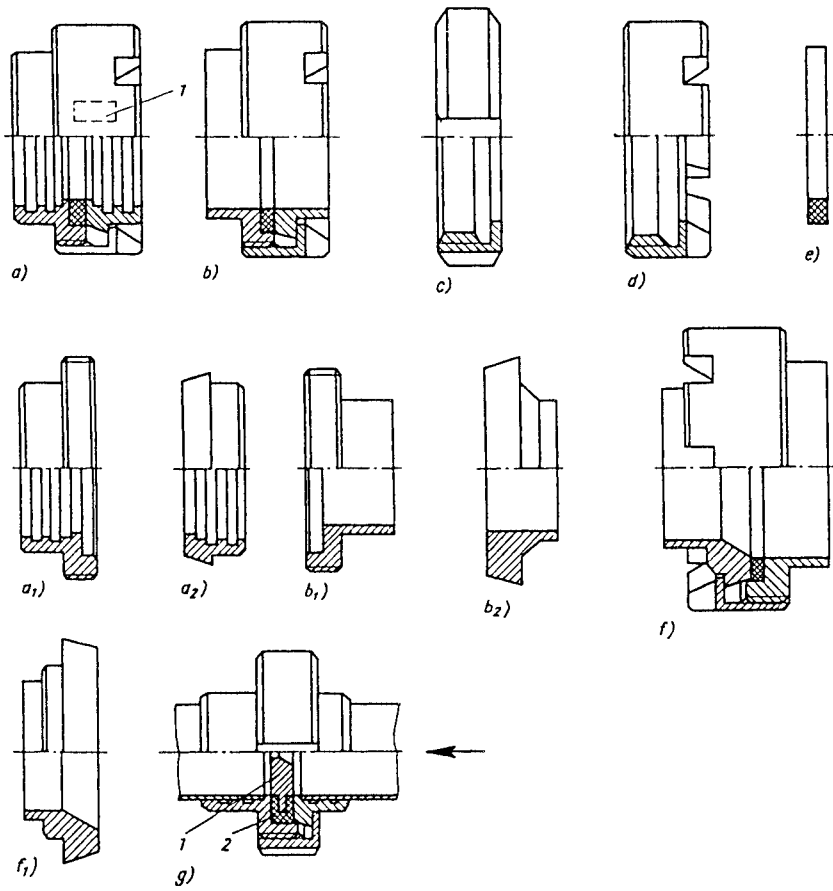


Figure 4./67 Pipe connections

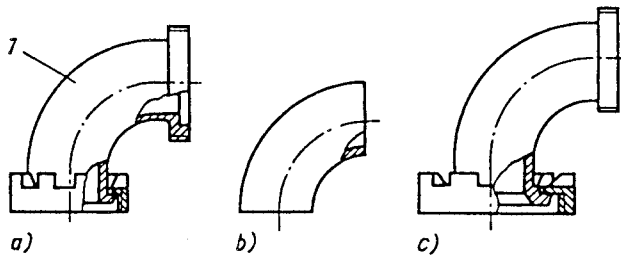


Figure 4./68 Pipe bends

Types of fittings.

Connection fittings. These serve to connect pipelines with each other or with auxiliary material and to change the direction or direct a flow (bends, T-piece). Devices may be installed in them for measurement (instrument inserts) as well as to control the flowing media (sight glass) or to prevent return flow of liquids (nonreturn valve). Examples of fittings are shown in Overview 4./9.

Thread connections, bends and T-pieces can also be designed in the form of reducing types, where the diameters of the openings are different.

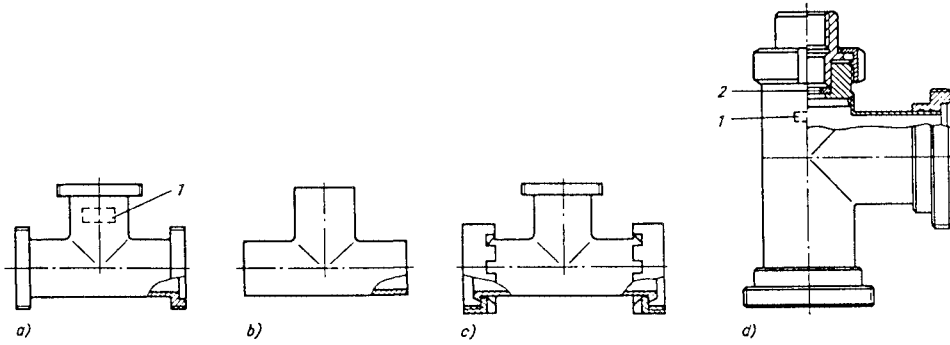


Figure 4.69 T-pieces

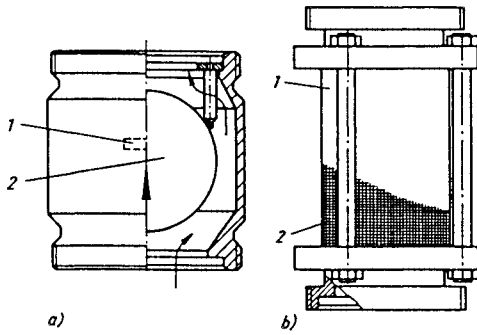


Figure 4.70 a) Check valve b) Sight glass

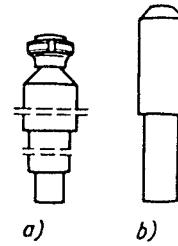


Figure 4.71 Ceiling passages

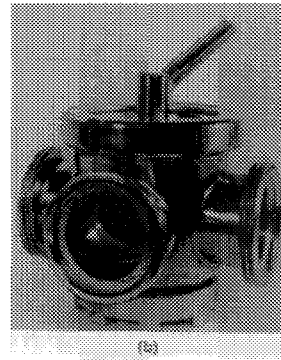
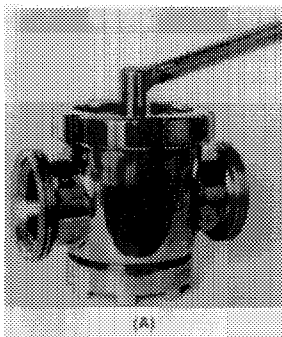


Figure 4.72 a) Two-way valve b) Three-way valve

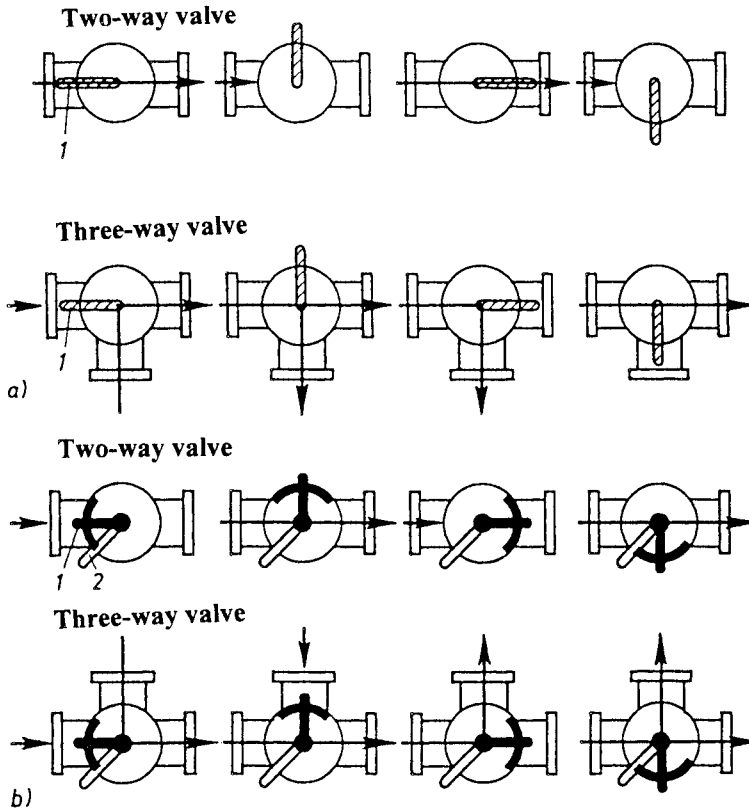


Figure 4./73 Flowsheet for two-way valves and three-way valves

a) Standard design (with solid plug) b) With hollow plug

(1) Lever (2) Safety lever

Cocks. These serve in the same way as valves and butterfly valves; their purpose is to block or modify the flow of the media. They can be designed as two-way valves or three-way valves (Figure 4./72). The conical plug (can be rotated, part of the cock) is pressed into the housing of the cock with the help of a thread. The cock also has a thread for pipe connections. A rubber gasket seals the cock between thread and plug. The lever, for operating the plug, shows the flow direction at the same time (Figure 4./73). Cocks with a hollow plug have an operating lever and a safety lever, which helps in pressing the plug into the cock.

Valves. In most cases, disk valves are used. They are characterized by having one or several disks in a housing, which open and close the valve (valve seat). In principle, they are operated with a wheel and a spindle, but these valves suited for automatic operation, and together with the stop valves they are key elements in process automation. Due to the humidity in dairies, pneumatically controlled valves are used (Figure 4./74). They are installed as stop valves or as routing valves with up to five connections.

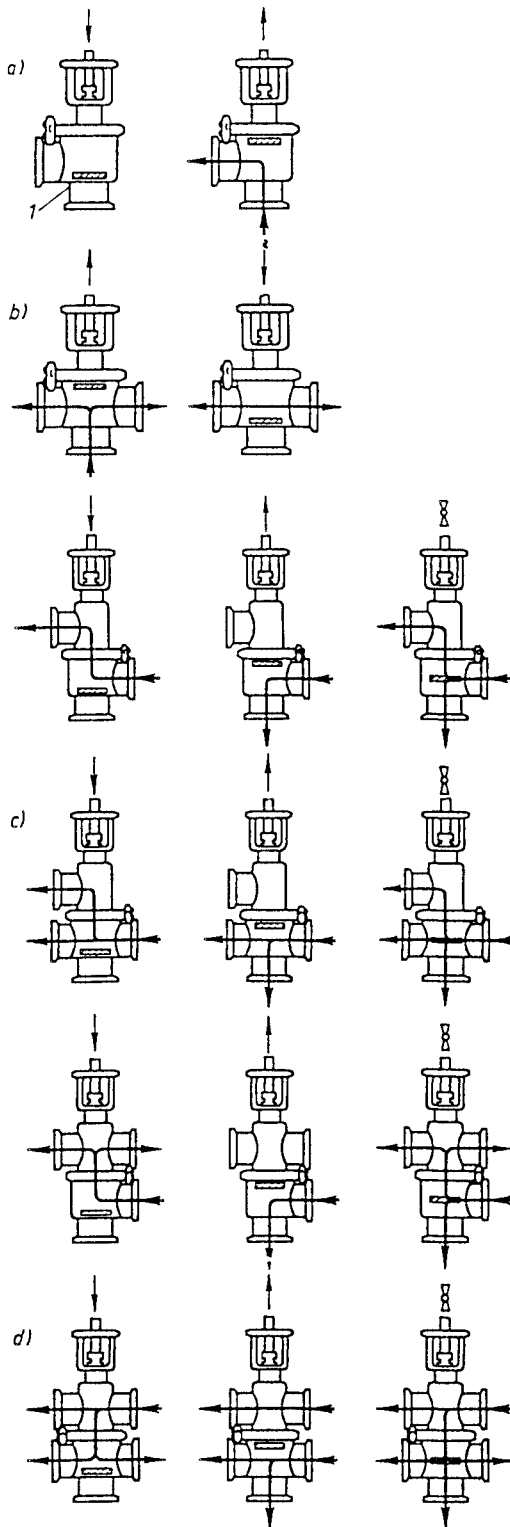


Figure 4./74 Flowsheet for pneumatic valves

a) Two-way shut-off valve

b) Three-way valve

c) Four-way valve

d) Five-way valve

(1) Valve disk

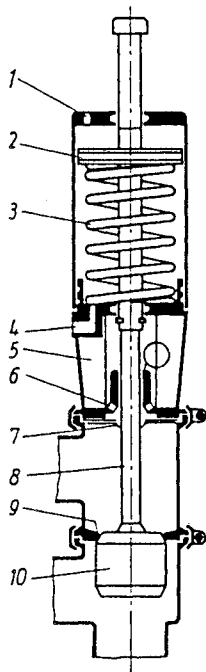


Figure 4.75 Pneumatic three-way valve, type SRC

(1) Upper compressed air connection (2) Piston (3) Spring (4) Lower compressed air connection (5) Free open space between pneumatic and product part ("open window") (6) Hole for leakage (7) Double action hygienic shaft seal (8) Valve shaft (9) Valve seat (10) Valve disk

Design and principles of a switching valve (Figure 4.75). The control housing of a switching valve has two compressed air connections. When the control air enters via the upper connection (1), a piston (2) and a connected valve disk (10) are pressed against the lower seat. When the control air is interrupted, a spring (3) pushes the valve disk against the upper seat (9). The valve can also be designed in such a way that both piston and valve disk can be moved in both ways; this requires control air to enter through the lower connection (4). An additional installation can move the valve disk into a neutral position, by interrupting the flow of control air, so that all product routes are kept open. Between the control housing and the product part of the valve there is a free, open space (5) so that mixing of product and control air cannot take place. At this location we also find the outlet of a hole for leakages which would indicate a leak in the valve shaft seal. The control air pressure is kept at 5–7 bars.

Microswitches can be installed in pneumatic valves to indicate the valve position and are operated directly by the valve shaft. (Figure 4.76). The exact valve position can be shown on a control display. Several pneumatic valves can be put into valve batteries or valve clusters.

- Automatically controlled valves must exclude mixing of incompatible liquids such as milk and cleaning solutions.

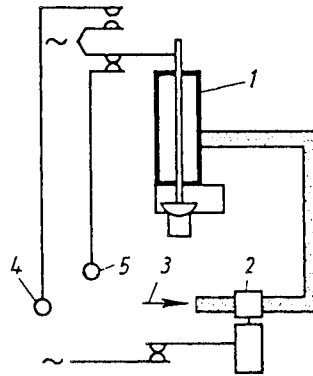


Figure 4.76 Position indicator of a pneumatic valve, controlled by a micro-switch

(1) Closed valve (2) Magnetic valve (3) Control air (4) Indication of "open" (5) Indication of "closed"

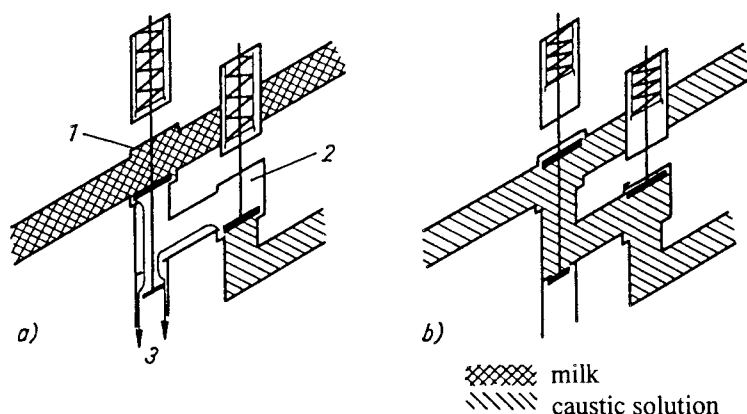


Figure 4.77 Leakage guards (schematically)

a) Operation b) Cleaning

(1) Leakage valve (2) Corner valve (3) Leakage outlet

Between the two media which are to be separated, a free space with an outlet must be created where leakage liquid can be drained without creating hazardous pressure in the valve.

The most reliable leakage guard is the installation of two independent valves, of which one is the leak valve (Figure 4.77). This valve is designed in such a way that a second valve seat in the bottom part of the valve is forced open when the valve closes. Leakage fluid can be discharged from the free space between the leakage valve and the second valve.

Stop valves. These serve the same purpose as cocks and valves. Between two pipes which are screwed together, there is a wide-area sealing gasket (food-grade, mostly silicon-caoutchouc), where a circular disk (valve) is installed and can be rotated axially (Figure 4.78). The opening angle (0–90°) can be modified with a simple lever (Figure 4.79). The closed valve is sealed absolutely tight to a pressure level of 10 bar.

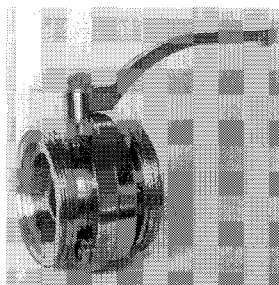


Figure 4.78
Stop valve with
thread end on both
sides and simple lever

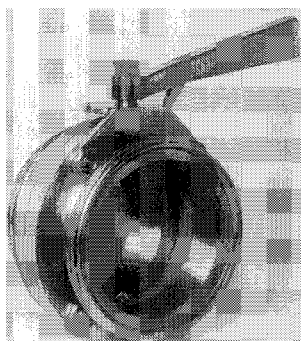


Figure 4.79
Stop valve with plier
lever

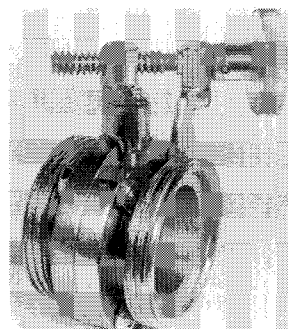


Figure 4.80
Stop valve with throttling
device

Stop valves can have identical types of connection (conical and screwed end) on both ends, giving them unique flexibility (Figure 4./80 and 4./81). Their simple construction and operating characteristics (temperature range -20 to $+120$ °C; for a short time up to 140 °C) as well as their potential for automatic control permit them to replace cocks and valves.

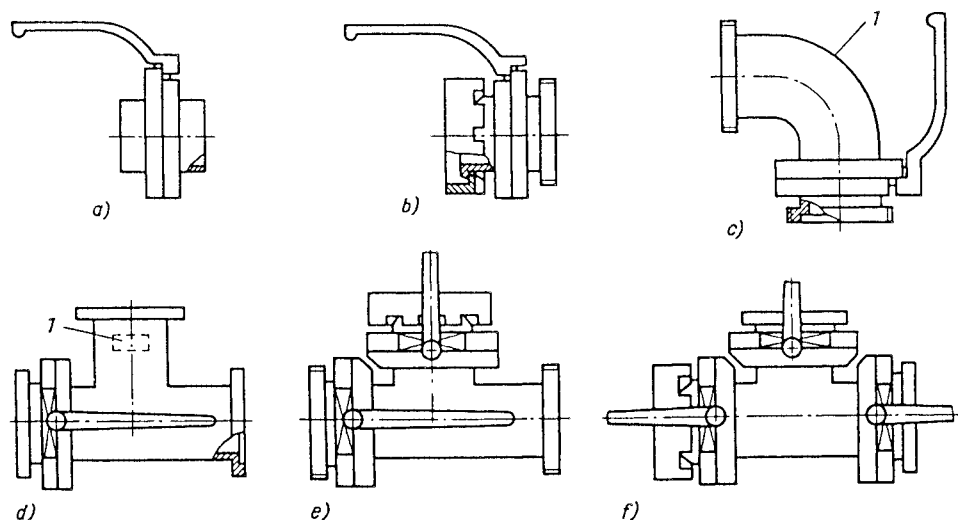


Figure 4./81 Utilization of multiway stop valves (selection)

a) One-way stop valve with welded end on both sides b) One-way stop valve; one side conical pipe with crown nut, other side threaded end c) Angle stop valve with double sided thread connection d) One-way stop valve in T-piece with double-sided thread connection e) Multidirection stop valve with left-sided threaded connection and stop valve and right-side thread connection, diversion with conical pipe, crown nut and butterfly valve f) Multidirection stop valve with left conical valve, crown nut and butterfly valve; butterfly valve right side and deviation with threaded end and butterfly valve (1) Identification location

Automatic remote control of the stop valves is done by control heads or control motors which are installed on top of the stop valves. They are either air opening, spring closing or spring opening, air closing. The former method has the advantage that in case of control air failure, the valve is closed by design, and mixing of products is impossible.

The valve shown in Figure 4./82 works according to the principle air opening, air closing and is operated by a radial angle motor. This requires control air pressure of 4–6 bar. The opening and closing times are in the range of 0.5–2 s and are subject to the length of the compressed air line. In case of failure of the control air or disturbances in the electricity supply, the stop valve remains in the last position. Its position can still be modified by using a auxiliary lever which is installed on top of the motor. The position of the valve is shown by an indicator.

A pneumatically controlled stop valve can be equipped selectively with either electrically or pneumatically controlled single or double action feedback for the end position of the valve; the control air pressure for the feedback is in the range 2.0–2.4 bar.

Operation of radial angle-controlled stop valves (Figure 4./82). The pneumatically controlled motor operates mechanically on the basis of a steep pitch. The operating piston (3) is guided axially by grooves (4). This guidance is done by the pins (5) which are con-

nected to the working cylinder, which are placed on rolls. In a piston (3) is a second pair of rolls installed at 90° to the grooves, which converts the movement of the piston into an angular movement of 90° by moving the journal that is housed on the bottom of the working screw-like cylinder. The angular movement is transmitted to the valve by a joint coupling. The control air enters and leaves through opening (11) and (12) in the working cylinder.

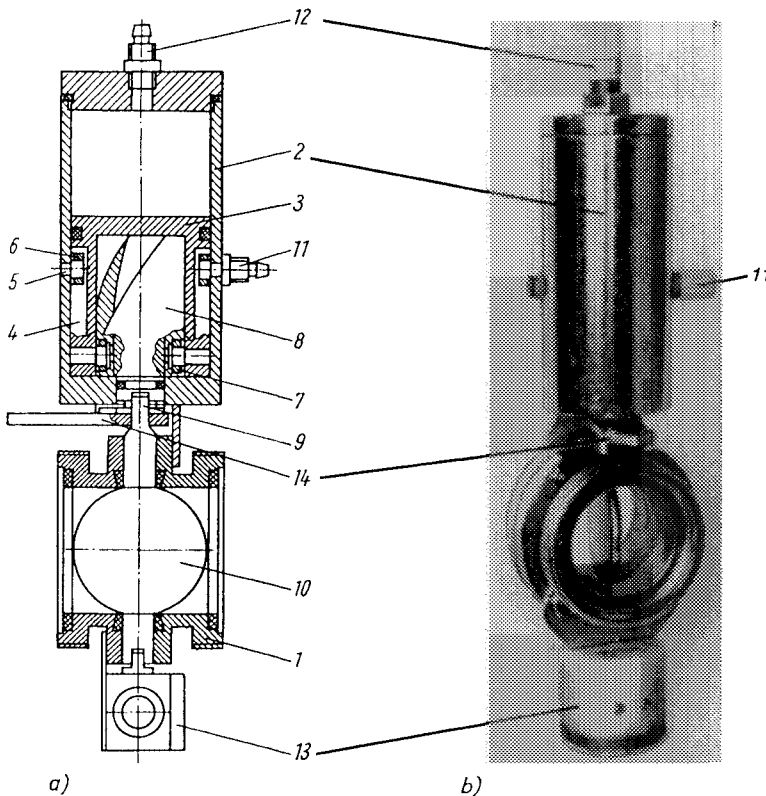


Figure 4.82 Pneumatically controlled stop valve with radial angle motor and pneumatic feedback

(a) Cross section b) Total view

(1) Housing of the valve (2) Working cylinder of the radial angle motor (3) Piston (4) Guiding grooves (5) Pins (6) Rolls (7) Second pair of rolls at 90° (8) Spiral grooved journal (9) Joint coupling (10) Valve (11) and (12) Connections for control air (13) Pneumatical feedback transmitter (14) Lever for manual operation

Several stop valves can be set up as a cluster (Figure 4.83). This cluster is installed on frames, and all connections for the control air are combined.

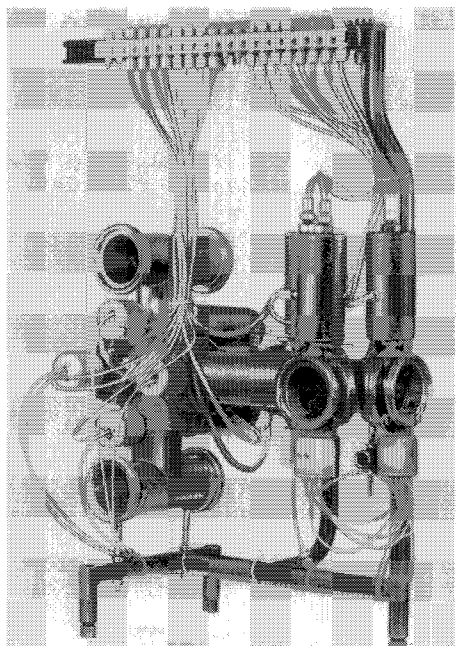


Figure 4./83 Pneumatically controlled valve cluster

4.4.4. Pumps

Pumps are machines used for the transport of liquid media; they transmit energy to the medium to be transported. Basically two principles are used:

- a) Transmission of mechanical work to the medium to be transported by using mass inertia, mainly centrifugal action (centrifugal pumps)
- b) Influence of pressure on the medium to be transported (displacement pumps)

A pump's application is based on its characteristics and operating performance. The characteristics are controlled by the design and type. The operating performance comprises the characteristic function of flow (flux) and pressure (also indicated in height or meters of water column) at constant operating conditions such as rpm (piston frequency) and viscosity of the medium.

The operating performance is shown by the pump operating curves. In these diagrams the flux is presented as a function of the RPM n , or the height h (or pressure p) is shown as a function of the flux (Figure 4./84)

The specific characteristics of milk and dairy products, especially the limited shear stress for products, permit only a limited selection of types of pumps (see Overview 4./10.). For parts in contact with the product, in most cases stainless steel or food-grade rubber or plastic is required as a material. Further, in most cases a CIP cleaning must be possible.

Overview 4./10 Types of pumps (Figures 4./85 to 4./91)

Type	Principle	Applications
Centrifugal pump (Figure 4./85)	<p>The liquid flows into a flywheel (1) and a centrifugal force is created due to its orbital velocity. The liquid then experiences a velocity increase, and the conversion from velocity into pressure takes place in the housing.</p> <p>Centrifugal pumps can be differentiated by their feeding system (axial Figure 4./86, radial Figure 4./87) and their configuration (number and design of housing). Apart from the single-stage pumps (with housing there are</p> <p>a) multistage pumps (in series) with consecutively installed pumps for a significant pressure increase and</p> <p>b) multistage pumps (parallel), set up in parallel for an increase in flow volume.</p>	<p>In dairies, mostly single-stage pumps are used for milk and other low-viscosity material in the low-pressure range up to 2 bar with flow rates up to 20 m³/h. Multistage radial pumps are used for the medium pressure range 2–5 bar, mostly for water.</p> <p>Centrifugal pumps are not self-priming; i.e., the liquid has to flow under pressure into the pump, either by hydrostatic pressure (free flow) or by priming with pumps (water-ring pumps), where a suction effect can be created.</p> <p>Control of the flow rate at constant rpm can be done by valves in the feed pipeline.</p>
Rotating displacement pumps	Displacement bodies rotate in a capsule or housing, and transfer the medium from the suction area into the pressure area.	Mainly used for the transport of highly viscous products e.g., quarg, cream, butter.
Capsule pump, rotating piston pump (Figure 4./88)	The zipper-like action of the displacement bodies or the teeth of a cog wheel is characteristic. A sealing gap is created when dynamically sealing the pressure area from the suction area, and a small amount of leakage flow passes through this gap with a high pressure drop.	The self-priming pumps are used for a pressure range of 4–10 bar. The volume flow is controlled by the rpm of the displacement bodies, itself controlled by a compensation gear.
Screw pumps (Figure 4./89), single shaft pump	Screw pumps with a flexible stator and a fixed rotor operate similarly to rotary piston pumps but are limited to self-priming. Feeding of the medium is preferably done at a lower hydrostatic level (level difference).	Low shear stress of the medium, well suited for cream and other fatty and paste products. Volume flow control same as for rotary piston pump.
Oscillating displacement pump, piston pump (Figure 4./90)	<p>The difference from rotating displacement pumps is in the valve-controlled inlet and outlet openings into the working areas and the linked pulsating flow. To smooth the impulses two or more working areas are set up in parallel (multiple piston pumps).</p> <p>At the first backstroke of the piston, the volume in area C is enlarged, thus reducing the pressure (according to the Boyle-Mariott law). A higher pressure is now imposed on the liquid level A and thus pushes the liquid via the suction pipe B into area C, where valve V₂ opens. During this operation the pressure in area D is greater, so that valve V₁ closes and the liquid cannot flow back. During the opposite piston movement, the pressure in area C is increased, valve V₂ closes and the liquid is pushed into area D via valve V₁</p>	Suitable for the transport of large quantities of water with a pressure increase, for boiler feed supply, especially as dosing pumps for low flow rates. Piston frequency and flow rate are controlled by a compensation drive. No stop valves in the pressure pipe!
Jet or injector pump (Figure 4./91)	Steam, air or other gases exit from the nozzle (1) at high velocities and enter the blending tube (2), which is surrounded by the transport medium, and have a suction effect on the liquid. Several nozzles with blending tubes can be installed in series, thus increasing the suction and transport capacity.	Used in boiler supply lines and vacuum evaporators. Can extract and transport water, steam or air.

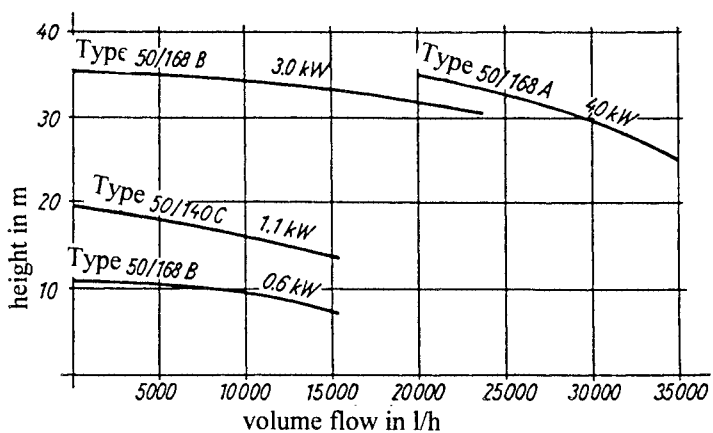


Figure 4./84 Operating characteristics of centrifugal pumps

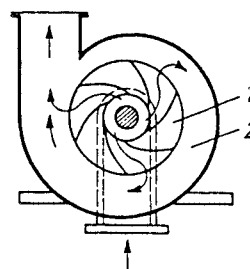


Figure 4./85 Centrifugal pump (principle)

(1) Flywheel (2) Housing

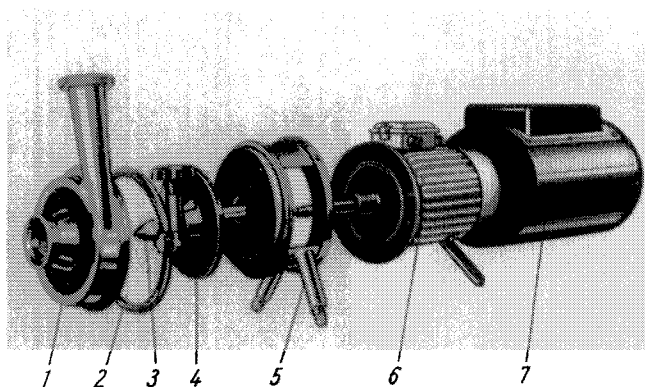


Figure 4./86 Centrifugal pump, type KRPO

(1) Chamber (2) Backplate (3) Flywheel nut (4) Flywheel (5) Housing (6) Motor with elongated shaft and improved bearing (7) Protective cover of motor

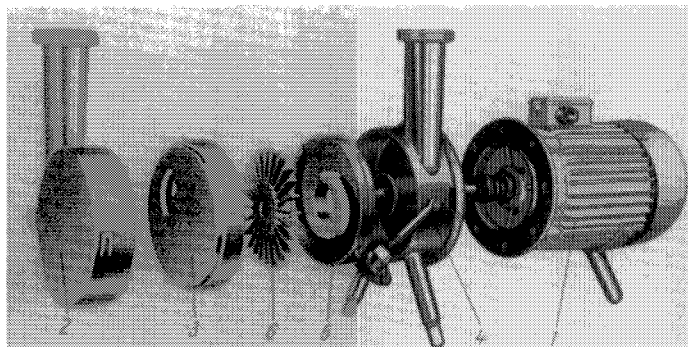


Figure 4./87 Starwheel pump, type KSP

(1) Electrical motor (2) Suction cover (3) Suction intermediate part (4) Pressure cover (5) Pressure intermediate part (6) Flywheel

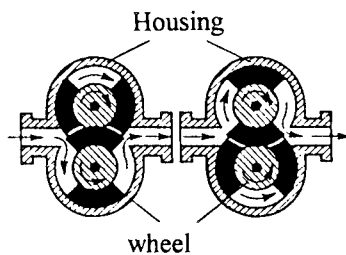


Figure 4./88 Rotating piston pump

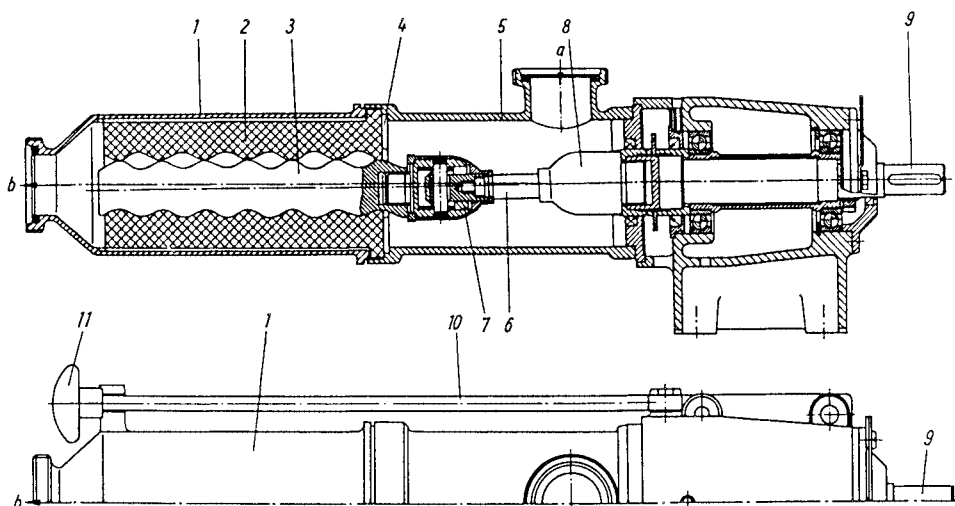


Figure 4./89 Screw pump, type UMQ (without drive and gearbox)

a) Product inlet b) Product outlet

1) Stator cylinder 2) Stator 3) rotor (transport screw) 4) Guiding plate 5) Pump cylinder 6) Shaft 7) and 8) Joints (sealed with rubber caps 9) Drive shaft 10) Tightening screw 11) Star nut

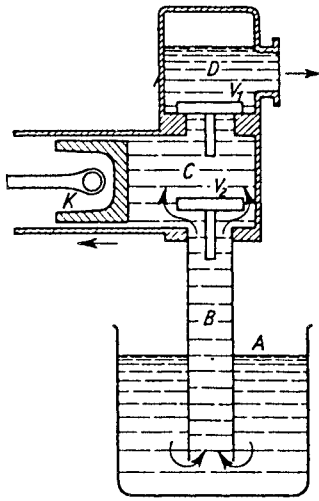


Figure 4./90 Piston pump

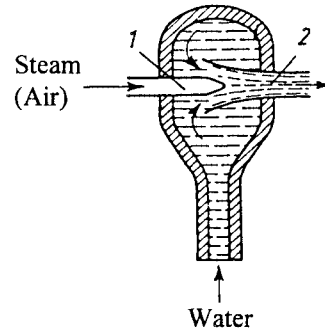


Figure 4./91 Jet or injection pump

4.4.5. Stirring elements

During the treatment of milk, numerous unit operations are linked by very specific mixing processes.

- Stirring is a mechanical operation for the equalization of temperature and/or concentration differences.

The main purpose of stirring is to manufacture solutions, emulsions, suspensions and dispersions of compounds as well as to obtain and maintain a defined distribution in the product which is to be mixed. Further stirring serves to incorporate or deaerate a blend.

Apart from the material characteristics of the product such as viscosity, flow behavior and shear velocity, other parameters such as the volume of the product, stirring vessel size and shape, required stirring and blending quality, sensitivity of the product and design of the stirrer are of paramount importance for the effectiveness of the stirring operation. Figures 4./92 to 4./94 show the basic forms of stirrers and their application in relation to the viscosity of the product to be stirred.¹

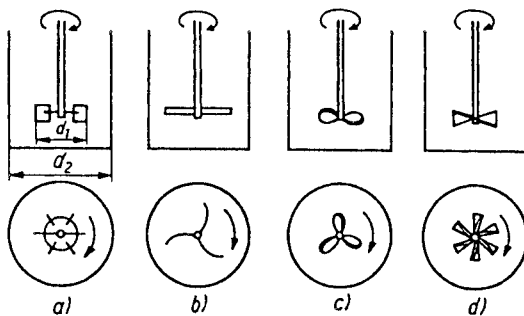


Figure 4./92 Stirrers for products with low viscosity ($\eta < 1 \text{ Pa}\cdot\text{s}$)

¹Source: Kessler, H.G. Lebensmittelverfahrenstechnik-Schwerpunkt Molkereitechnologie, München-Weihenstephan: Verlag A.Kessler, 1976.

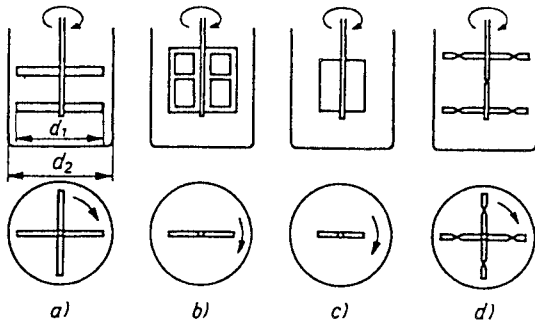


Figure 4./93 Stirrer for products with medium to high viscosity ($\eta \approx 0.5\text{--}5 \text{ Pa}\cdot\text{s}$)

In order to have thorough mixing and to avoid rotation of the liquid in the vessel, the stirrers shown in Figure 4./92 and Figure 4./95 are installed either slanted or radially.

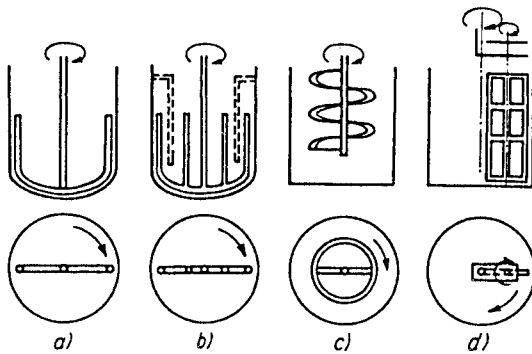


Figure 4./94 Stirrer for products with very high viscosity (η up to $100 \text{ Pa}\cdot\text{s}$)

a) Anchor stirrer (d/d_0 0.8–0.98)
 b) Finger stirrer with baffles (d/d_0 0.9–0.98), c) Helicoidal stirrer (d/d_0 0.96–0.98) d) Grid stirrer with planet drive, rotating in two axes

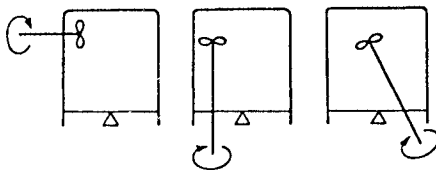


Figure 4./95 Possible installations of stirrers in vessels

5 Market Milk, Milk Drinks and Cream Products

5.1. Market milk, industrial milk

5.2. Milk drinks

5.3. Cream products

5.4. Desserts and cream products

5.5. Reconstituted and recombined milk

5.6. Milk imitations



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5 Market Milk, Milk Drinks and Cream Products

5.1. Market milk, industrial milk

5.1.1. Terms and categories

Consumption of milk in its original state and form has been known to man for ages and is the prevalent type of consumption in many—mostly underdeveloped—countries. Raw milk is still offered for direct human consumption in countries where milk is produced commercially by dairies. This milk is called as “milk direct from the farm,” “fresh milk” or “open milk.” We find mainly two types:

- a) Raw milk is neither heated nor treated in a dairy, but its natural composition (e.g., fat content) can be modified. It can be sold only by labeling it “raw milk, to be boiled before consumption” due to the hygienic risks involved.
- b) Certified milk is commercialized in a nonmodified form in its natural composition, raw (i.e., nonheated), in a sellable prepacked form. Its production is controlled by the authorities, and strict criteria must be met for the health of the cows, characteristics of the milk, personnel, treatment, packaging and distribution.

Further, milk is offered from ecologically managed farms, which must meet special criteria with regard to total plate and cell count but have to comply at least with the requirements for “raw milk.”

Fresh milk, also labeled “milk,” is a processed milk. A proper heat treatment before the milk is commercialized is absolutely necessary due to the hygienic characteristics of the raw milk, which contains a multitude of germs including pathogens, resulting in a health risk to the consumer and rapid spoilage of the milk.

- Heat-treated milk is made from raw milk, treated in a dairy, and must be pasteurized, processed with UHT or sterilized according to officially recognized heat treatment processes.

Therefore we distinguish between the following types:

- a) Pasteurized milk or high-temperature pasteurized milk
- b) UHT milk
- c) Sterilized milk

The manufacture of high-heat pasteurized, UHT or sterilized milk can be done with raw milk which has been thermized or pasteurized in a different plant. Before the second heat treatment it must have a positive peroxidase treatment.

Apart from the type of heat treatment, fresh milk differs in fat content. The following classification can be made in terms of the fat content (e.g., a predefined nutritional program in relation to the energy requirements) or the importance of specific characteristics of the product such as taste:

- a) Milk with a natural fat content of 3.5 to 4.5%
- b) Standardized milk with a fat content of 1.0 to 3.5%
- c) Fat-free milk (skim milk, decreamed milk) with a fat content of < 0.04%

For heat-treated fresh milk the following grades exist in Germany:

- a) Fresh milk with a natural fat content, with a minimum of 3.5%
- b) Fresh milk with a standardized fat content of 3.5%
- c) Partially skimmed or fat-reduced milk with a fat content of minimum 1.5 and maximum 1.8%
- d) Skim milk or decreamed milk with a maximum fat content of 0.3%

Other types are homogenized milk (most of the fat-containing milks are homogenized), vitaminized milk (enriched mostly with vitamin D), protein-enriched milk (e.g., with caseinate or protein concentrates), milk made from milk powder (e.g., reconstituted milk, made from dissolved milk powder), recombined milk (made from milk components, see also Section 5.5) and others.

Market milk comprises—apart from types described above with a nearly natural taste and pH value—milk drinks and cream products. These are products “based on milk,” manufactured from industrial milk.

- Industrial milk is raw milk which is destined for processing or market milk or frozen milk made from raw milk which has been subjected to a certified physical treatment such as heat treatment (thermization, pasteurization, UHT process). It can be modified, as long as the modification is based on the addition and/or removal of natural components of milk.

Industrial milk is handled and treated in approximately the same way as market milk. Market milk is considered a complete food for mankind, having all nutrients and vitamins. an adult person can cover one-fifth of his daily nutritional requirements by consuming 1 l of market milk. Market milk is essential for feeding children. Nutritionist recommend a daily consumption of 0.5 liter of milk per person.

5.1.2. Technology

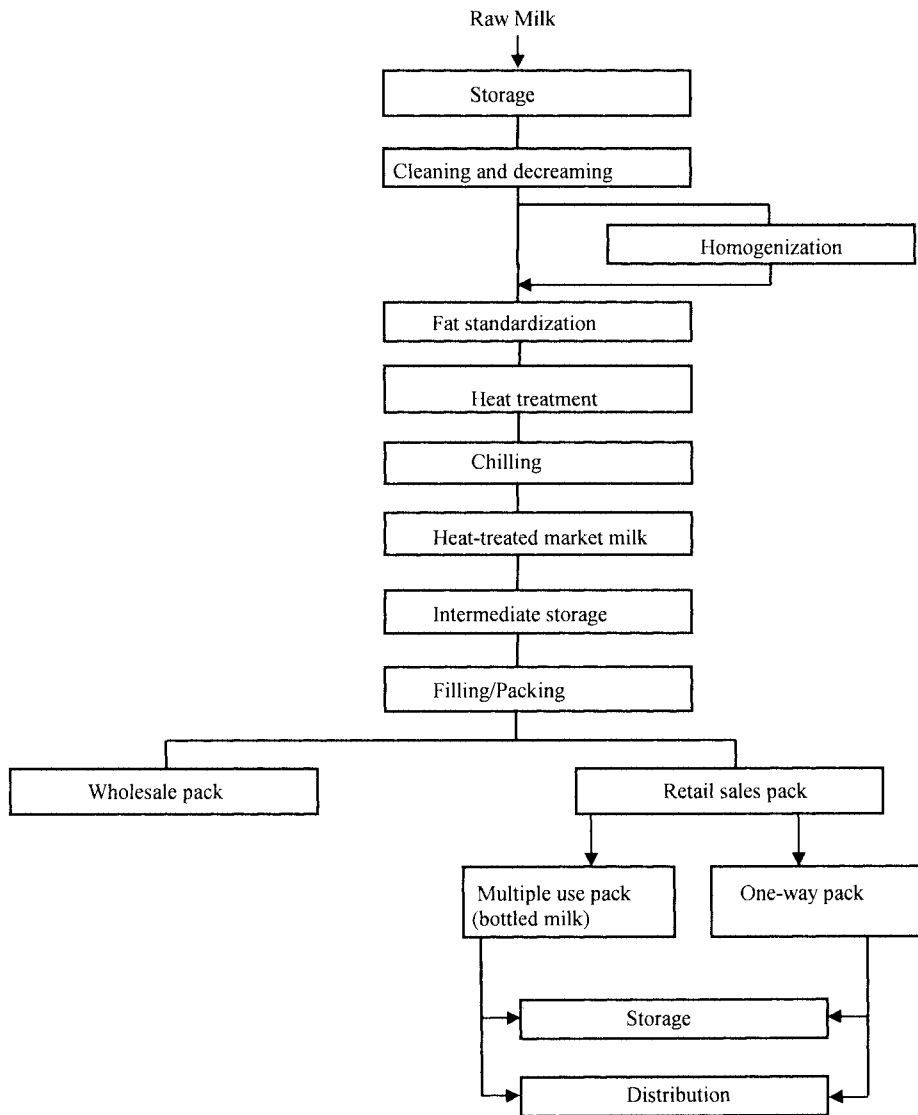
Heat-treated market milk is manufactured from raw milk, which must comply with the standards described in Section 2.7.3.1. Further, the milk must be cooled to 6 °C after reception and must be stored at this temperature until the next heat treatment, unless it is processed within 4 hours after reception. In general, raw milk should be processed within 36 hours and should have a maximum total plate count of 300,000 germs/ml. If the plate count is higher, the milk cannot be converted into market milk. The dairy is responsible for the corresponding checks and controls.

Overview 5./1 shows a flowsheet describing the general processing steps. Basic unit operations in dairy technology, such as storage, cleaning, homogenizing, fat standardization, heat treatment and cooling, have been described in detail in Section 4.1. Here we discuss only the intermediate storage and the filling/packing operation (Section 5.1.3).

Intermediate storage of milk. The heat-treated milk passes through intermediate storage for the following purposes:

- a) Guaranteeing a continuous supply during filling
- b) Separating the filling operation from the manufacturing operation (shift operation)
- c) Monitoring of milk quality
- d) Standardization of the fat content (if standardization is not done during the decreaming stage or fine-tuning of the fat content)

Overview 5./1 Flowsheet for the production of market milk



The intermediate storage of market milk is done in vessels, which must comply with requirements in addition to the ones in Section 4.4.1.2:

- a) No influence of the materials on the stored milk
- b) No temperature increase, e.g., by insulating the tanks
- c) Availability of stirrers, level controls and thermometer
- d) Acceptable cleaning and disinfection devices, preferably equipped with spray nozzles for CIP

During intermediate storage milk should not show a quality deterioration due to external influences. Therefore tanks (silos) are installed in a separate section (tank area). Here the requirements are:

- a) Light and well ventilated, tiled walls and acid-proof floor
- b) Short piping connections to the filling area
- c) Low bacterial load in the air (eventually the air has to pass through a filter or through a UV treatment)

5.1.3. Packaging of market milk

Basics

Legislation prescribes proper filling of market milk on suitable filling lines. Here we distinguish between filling and packing from an operational point of view. In most cases, packaging means the outer shell or pack.

- Enclosing is an action whereby a product is protected by a primary enclosure or primary pack. This enclosure or pack/container which is in contact with the food is also called a wrap(around).
- Filling is the insertion of one or more products, enclosed or not, into a pack/container. This container is also called packing.

According to the packaging regulations, we distinguish between the following types (valid for all classes and types, not only for market milk or dairy-based products):

- a) *Transport packs*. Barrels, cases, bags, including pallets, cardboard boxes, foam trays, shrink-wrap laminates or similar, which are part of the transport pack. They serve to prevent damage to the product during the transport from manufacturer to consumer. They are used for safety reasons.
- b) *Sales packs*. Closed or open containers and enclosures of products such as cups, blisters, cans, pails, barrels, bottles, canister, cardboard box, boxes, bags, trays, plastic bags or the like, which are used by the consumer for the transport and/or until the products are consumed.
- c) *Wraparound packs*. Laminates, blister, cardboard boxes or similar types, which serve as additional packaging of the sales pack, permitting distribution for self-service purposes, making pilferage more difficult and/or serving for advertisement purposes.

Beverage packs are containers which are filled with any type of liquid food and designed for liquid consumption, excluding yogurt and kefir. The packaging has one purpose, i.e., to enable the product to be transported and commercialized. Therefore it must meet the following requirements:

- a) *Maintaining quality*, i.e., protection of the product against harmful influences such as foreign bodies, dirt, air, humidity and light (especially during longer storage). In addition, there must be no reaction between packaging material and product.
- b) *Handling characteristics*, i.e., easy filling, suitable closure (must be designed for easy recognition of the opening), shelf stable, stackable, space efficient, light and cheap, good advertising carrier, sufficient rigidity to protect the product.

- c) *Reusability or reutilization*, i.e., the container should be fillable multiple times or should be recyclable after utilization.
- d) *Packaging materials* must be approved as food grade, i.e., nontoxic, should not react chemically with the product, should not be softened by the product, and should not influence the product's taste and odor.

Tanks, churns and other containers, which are in contact with milk should have smooth inner surfaces and be made from material which is corrosion-proof and easy to wash, clean and disinfect. They should not influence the milk in any way or harm people's health.

Other requirements are that the hygienic filling operation is done in suitable rooms, that the containers are protected by enclosures, and that they are stored in areas free of dirt and insects.

Enclosures and packs should not be reused, except for multiple-use packs which are properly cleaned and disinfected before being reused. The market milk packs must be sealed immediately after filling in an automatic way. The products must be transported immediately after packing to hygienic and acceptable storage rooms.

Types of packaging and systems

Packaging is the most expensive operation—from a technical, material and economic point of view—for market milk and other dairy products. Therefore numerous criteria must be considered in the selection of the form of packaging and the packaging system. Of interest are economic and ecological aspects as well as legal considerations as prescribed in the packaging regulations.

In order to reduce waste material, legislation, by definition, favors a multiple-use system, and we should foresee an increase of >25% of this form for liquid dairy products. Further, manufacturers and trade organizations are compelled to accept packing material (transport packing, outer packing and sales packs) which is returned, which influence the design and selection of the packaging form.

In Germany, the return of used packing material is done by the Dual System, which promotes the recycling of packaging material. Packages which are recycled by this system or manufacturers participating in the recycling system are permitted to use the logo "Green Point."

A proper evaluation of forms of packaging and systems is still unclear, difficult and contradictory, above all for ecological reasons. Clear statements (objective and multi-functional) are needed concerning packing materials and systems (so-called ecobalance) which include all processes, i.e., manufacture, multiple use and waste handling, and they must show the effects on ecocycles, i.e., impact on air, water, soil, and waste disposal.

The following classification of packaging forms can be made :

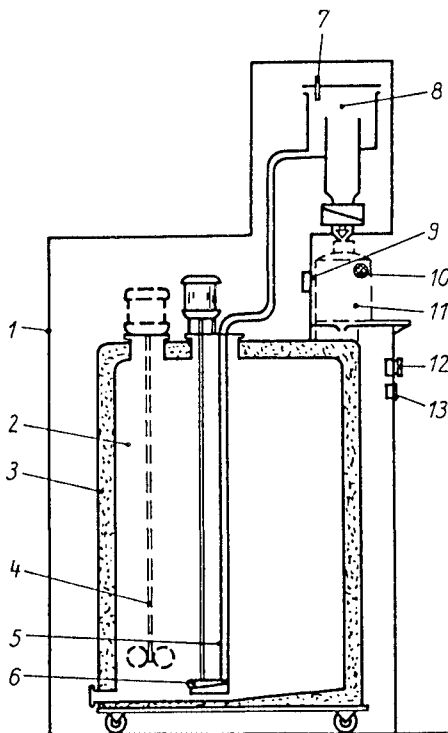
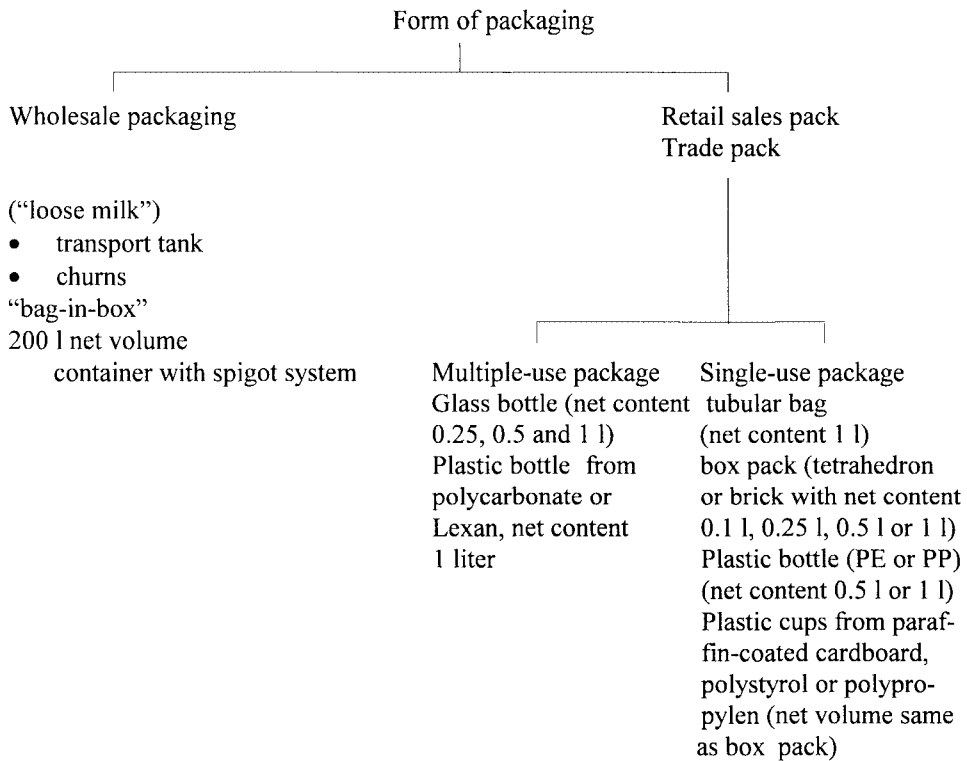


Figure 5./1 Scheme of a self-dispensing system, system Eisdorf

- (1) Housing with electronic control panel
- (2) Stainless steel milk tank, volume 240 l
- (3) Insulation (4) Stirrer (5) Filling and return pipeline (6) Pump (7) Overflow safety switch (8) Measuring device (9) Filling safety switch (10) Overflow safety switch (11) Milk bottle (12) Filling button (13) Signal lamp

5.1.3.1. Food service packaging

Here “loose milk” is used, which is not filled in retail sales packs.

Wholesale customers such as kitchens, restaurants, hospitals, and military facilities use mainly transport tanks, rarely churns, but can also use larger containers made of plastic, which have a level indicator and a dispensing device.

- These containers must be cleaned properly and disinfected before filling.

Bag-in-box containers are also used. This multilayered laminated bag has a net volume of 2–200 l and is transported in corrugated cardboard containers or wire-mesh cages.

In order to introduce this form to the retail trade, self-dispensing systems (Figure 5./1) have been developed. The consumers simply fill their own container with the desired quantity of milk, and after using up the contents, they clean the container in a normal way in the household. Other types of containers or cups can be filled in the same way, making this system very suitable for schools, canteens and others. This self-dispensing system can also be used in automatic installations.

5.1.3.2. Multiple-use containers

The basic characteristic of a multiple-use container is, that they are returned via the trade to the dairy after being used and that it is refilled (either aseptically or with a sterilization) after having been cleaned and disinfected.

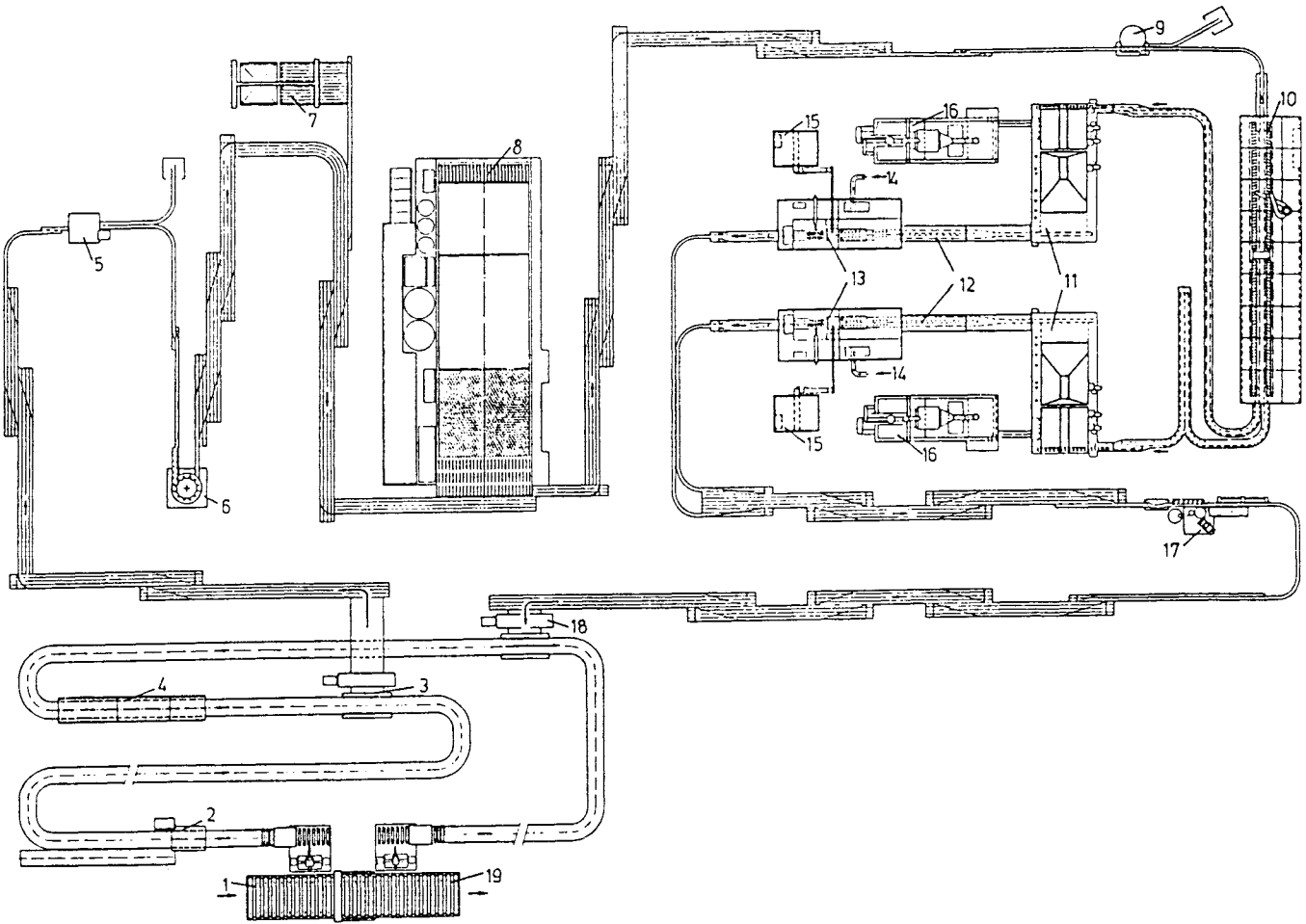
The most common multiple-use container is the glass bottle, made from clear, uncolored glass. Advantages are that according to the glass quality the bottles can be recycled 30–40 times and broken glass can be reused easily. Another advantage is that the product is clearly visible to the consumer and thus causes positive associations, which the consumer believes to be related to high-quality food. For UHT products, colored glass is used in order to protect the contents from negative light influences during the longer shelf life. The product still remains visible and contributes to its own advertisement.

The requirements for the return and cleaning of the containers are a disadvantage, as well as the high acoustic stress during cleaning and filling, a higher tare weight of the bottles and the increased space requirements compared to the one-way containers, and the risks on breakage and injuries.

Another types of multiple-use container is the plastic milk bottle, made from polycarbonate or Lexan, which have the advantages of a glass bottle and simultaneously those of a one-way container. These include a very low tare weight (tare weight about 70 g), easy handling (about 10% packing material, 90% product), no risk of breakage and ability to be reused about 70 times. These bottles can be sterilized at 121 °C. However, the cost of manufacture is slightly above those of glass bottles.

The containers are closed with aluminum caps (pressed on site), laminates for heat sealing, as well as premanufactured twist-off caps made from plastic-coated lacquered metal sheets and other plastic closing devices, which permit reuse of the bottles but also show any tampering.

Process lines for bottled milk. The basic difference in the process lines are in the type of processing and filling (pasteurized or UHT products). The basic principle is the same; for the manufacture of long-life products, the lines must also be equipped with aseptic or sterilization equipment.



The process line in Figure 5./2 has been designed for filling of UHT products and has a capacity of 24,000 containers per hour. Apart from the standard glass milk bottle, plastic bottles and bottles with a wide mouth can be used. Containers with the following basic dimensions can be used: net volume 90–1500 ml, diameter 50–90 mm, height 90–247 mm. The process line contains all elements which are necessary for automatic cleaning, disinfection and sterilization of the containers; filling, sealing and labeling as well as cleaning and disinfection of the transport crates.

All signals required for automatic control are obtained by sensors of different types and principles (light barriers, induction sensors) and are processed in a computer.

Process. Pallets with the empty packing material are transferred by a forklift from the warehouse to the destacking unit, where the crates are removed in layers and then separated. The crates are transferred to a control point, where nonstandard crates are recognized and removed. Crates and bottles are separated in the crate unpacking unit. The crates go to the washing station, where they are cleaned with overflow water from the bottle washing machine. The bottles are transported by parallel moving belts (which also serve as buffer zones and contribute to uninterrupted operation in line with the capacity of the individual machines). Nonstandard bottles are removed at a control point (5). Caps are removed from the bottles at station (6) (cap removal), and the bottles are then transferred to the bottle washing machine for cleaning and disinfection. If necessary, e.g., for capacity increase or due to interruptions, bottles can be fed into the line at station (7).

For nonaseptic products, i.e., the filling of pasteurized products, the cleaned bottles are passing through an automatic cleanliness control station (9) and reach the filling, closing, labeling and packing area.

For aseptic products such as UHT products, the cleaned bottles pass the cleanliness control station and go to a rinsing unit (10). Here they are pretempered and presterilized with steam, in order to increase the microbiological safety. The transport belts after the rinser are encapsulated in order to avoid contamination with ambient air. For reasons of capacity adjustment, the aseptic section (sterilizer, filler and sealer) have been doubled.

The bottles now reach the sterilizer (11) where, after preheating hydrogen peroxide vapors are condensed on the entire inner and outer surfaces of the containers. After a defined residence time, the condensate is dried off with sterile hot air. The bottles are inverted, and a blow tube is inserted through which the sterilizing medium is injected into the bottle and distributed evenly. With acid product (pH < 4.5), a sterilization with saturated steam is sufficient. The sterilization units are supplied with hot air, sterile air, hydrogen peroxide and steam by the aseptic supply units (16).

The bottles are then transferred via the sterilization tunnel (12) to the filling and sealing machines (13), where the filling devices are maintained under aseptic conditions by complete encapsulation and sterile air (slight overpressure). Filling systems are selected as a function of the product; for low-viscosity products flow control devices are used such as weighing devices; for products with foaming characteristics submersed tubes are used, and for high-viscosity products including those with particles up to 12 mm in diameter piston filler are used.

Figure 5./2 Process line for bottled milk with aseptic filling (maximum equipment)

(1) Depalletizer (2) Crate control (3) Crate unpacking (4) Crate washing machine (5) Non-standard bottle inspection (6) Cap removal (7) New bottle infeed (8) Bottle washing machine (9) Bottle cleanliness control (10) Rinsing (11) Sterilizer (12) Sterile tunnel (13) Filling and sealing with integrated seal sterilization (14) Infeed of the sterile product from the UHT process (15) Cap infeed (16) Aseptic supply unit (17) Labeling (18) Crate packer (19) Palletizer

The headspace can be sterilized in the sealing units before the seal is applied. Depending on the sealing type, a plastic, twist-off or heat seal can be applied. The closed bottles are now passed through the labeling unit (17) and are then transferred via the buffering belts to the crate packer (18) and palettizer (19).

The capacity of the process line for aseptic filling is basically controlled by the bottle washing machine and the filling and sealing machine, which are described in detail hereafter.

Bottle washing machine. Its main purpose is to remove all organic and inorganic residues (dirt) from the inside and outside of the bottle (cleaning) and to inactivate existing microorganisms (disinfection). Labels must be removed from labeled bottles.

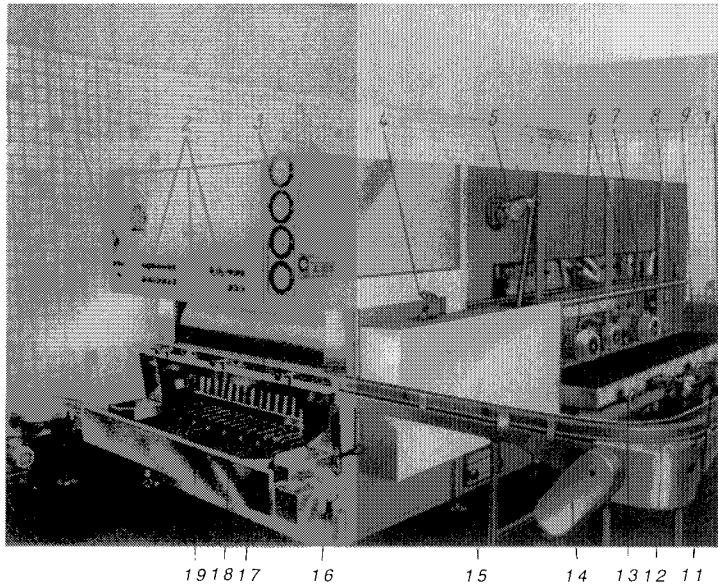


Figure 5./3 Bottle washing machine, type MDG

(1) Main switch (2) Control buttons (3) Remote thermometer (4) Fresh water valve (5) Manual drive element for upper drive (6) Pumps for water and lye spraying (7) Thermometer for sprayed lye (8) Thermo control for soft lye (9) Steam valve for soft lye (10) Overflow pump (11) Valve for diversion flow during indirect soft lye heating (low-pressure steam) (12) Steam valve for spray lye (13) Steam valve for warm water (14) Drive for bottle discharge belt (15) Butterfly discharge valve for soft lye (16) Drive for bottle infeed belt (17) Bottle discharge (18) Infeed table (19) Moving table for bottle infeed

Cleaning and disinfection are done by physical and chemical actions. The physical action are achieved by the spraying pressure of the cleaning solutions, by heat and—especially for smaller and older machines—by rotating brushes.

Chemical action is achieved by cleaning and disinfection solutions. Used cleaning and disinfection solutions are collected in separate tanks and are neutralized before discharge into the wastewater system.

Automatic brushless bottle cleaning machine type MDG (Figure 5./3). This machine has a wide utilization spectrum; i.e., it is suitable not only for the sizes of milk bottles but also for other types of bottles (beer, wine and others) and wide-mouth jars.

The operating principle is shown in Figure 5./4. The bottles which are to be cleaned are transferred on a rotating conveyor chain through the machine. The sequencing time can be controlled variably and is in the range of 20 s and 6 s, resulting in a total residence time of 35 min and 10 min and a capacity of 3000 to 16,000 bottles per hour.

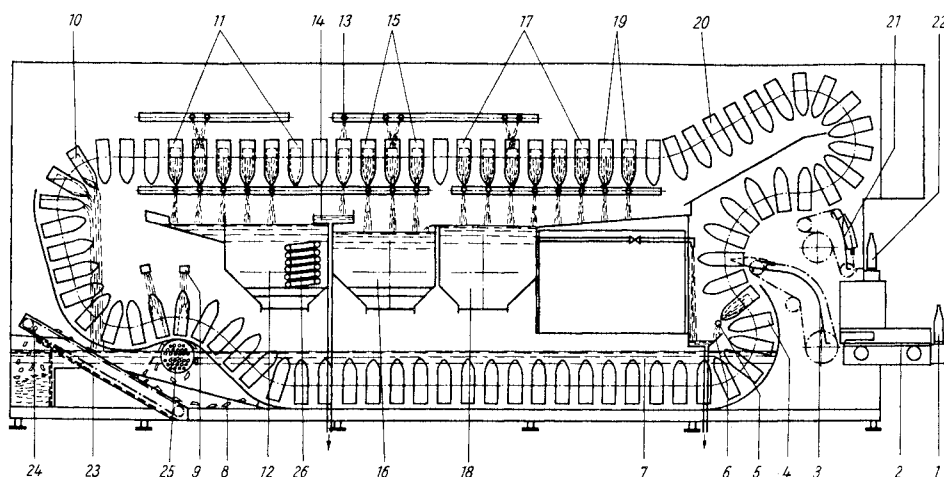


Figure 5./4 Basic flowsheet of bottle washing machine, type MDG 32, capacity 3000–16,000 bottles per hour

(1) Bottle infeed conveyor belt (2) Infeed table (3) Infeed lifting device (4) Bottle holder (5) Pre-rinsing, 40 °C, 2.8 bar, 2 m³/h (6) Collecting pipe for wastewater (7) Soft lye, 65 °C for cleaning agent RF or 50–55 °C for cleaning agent RDF (8) Settling chamber for glass pieces (9) Label removal (10) End of the soft process (11) Spray lye 80 °C, 3.4 bar, 50 m³/h (12) Spray lye trough with heating and pump (13) Intermediate spray, 50 °C, 2.8 bar, 3.5 m³/h (14) Collecting trough for intermediate spray and overflow (15) Warm water II, 50 °C, 2.7 bar, 27 m³/h (16) Warm water trough II with heating and pump (17) Warm water I, 25 °C, 3.5 bar, 50 m³/h (18) Warm water trough I with pump (19) Fresh water spray, 12 °C, 2.5 bar, 6.4 m³/h (20) Drip zone (21) Bottle discharge chute (22) Bottle discharge conveyor belt (23) Label sieve (24) Blow pipe (25) Tubular heater (26) Tubular heater

Filling and sealing machines. The machines are designed as monoblocks; i.e., both filling and sealing unit are integrated into one block. This means that the bottles can be sealed immediately after filling, and contamination of the bottles is nearly excluded. Filling can be done based on two principles:

- a) By vacuum; i.e., air is removed from the bottle, and the milk is transferred free of foam into the bottle under atmospheric pressure, which exerts itself on the liquid (Figure 5./5).
- b) By gravity (static pressure) of the liquid; air is displaced by the higher liquid pressure from the bottle (Figure 5./6).

All machines with higher capacity use the vacuum filling method.

Filling and sealing machine type VW 24. This machine (Figure 5./7) has a capacity of 12,000 bottles per hour. All sizes of bottles can be used; a simple adjustment of the inlet and outlet star wheel is required for the filling and sealing machine for different sizes of bottles.

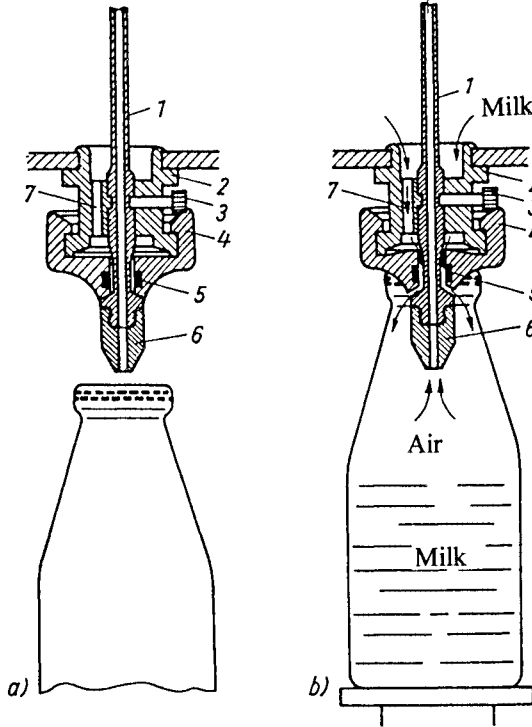


Figure 5.5 Principle of vacuum valve filling

a) Closed b) Opened

(1) Air pipe (2) Valve body (3) Guidance pin
(4) Rubber membrane (5) Metal ring (6) Rubber nipple (7) Overflow drill hole

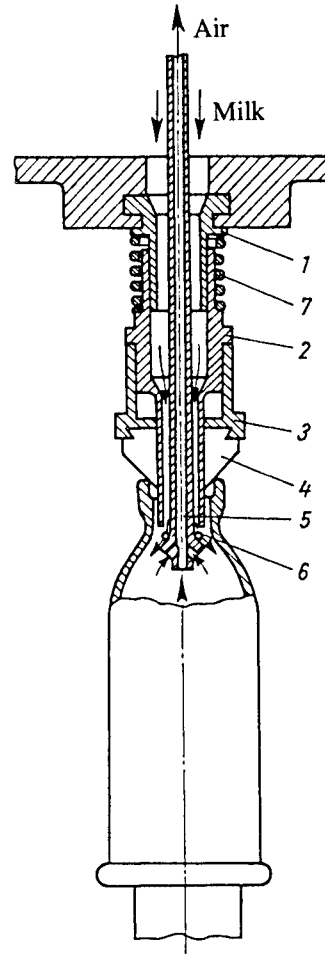


Figure 5.6 Principle of pressure-spring level filling

(1) Valve body (2) Closing rod (3) Outer rod
(4) Rubber (5) Air pipe (6) Gasket (7) Spring

The principle of this machine is that each cleaned bottle is pushed onto an individual bottle support (3) and enters the process. The bottle neck is pushed against the rubber membrane of the filling device (4) (for design see Figure 5.5). Air is removed from the bottle due to the vacuum which exists in the upper part of the filling vessel (5). Simultaneously, the opening between the membrane and the filling tube is released by the push of the bottle against the rubber membrane; milk enters the pressure-reduced volume of the bottle. Once the milk has risen to the level of the lower drill hole of the filling tube, no more air can be removed from the bottle, and the filling operation is terminated. During the filling cycle, the bottle passes through a complete circle of the rotating filling vessel, reaches the outlet star wheel, is removed from the descending bottle support, and is transferred by a conveyor belt to the sealing machine.

The advantages of vacuum filling are that the filling process is accelerated, milk losses are reduced, damaged bottles are not filled, filling tubes have no dripping losses and filling is foam free.

The closing machine is directly linked to the filling machine. It is equipped with a fixed bottle support and movable closing elements (14), which must be adjusted to the bottle height. An inlet star wheel transfers the bottles to the cap depositing device (13).

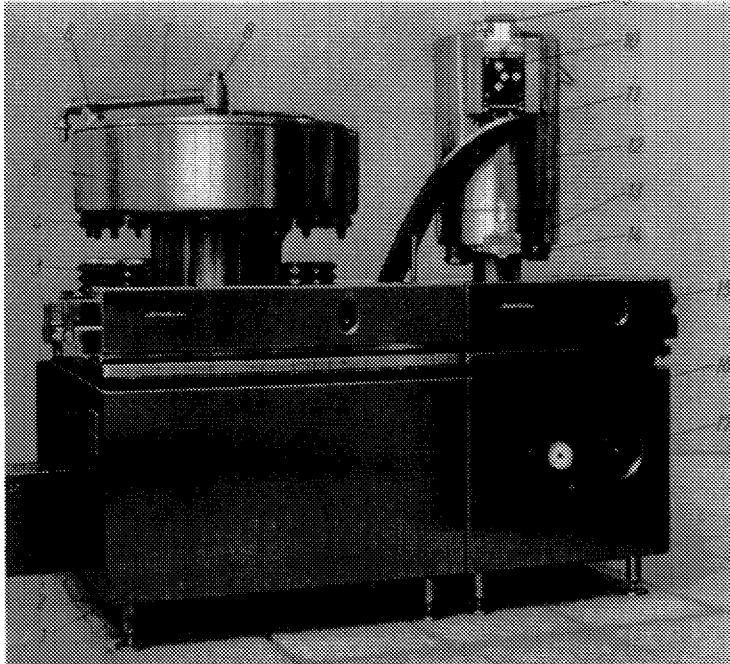


Figure 5./7 Bottle filling and capping machine type VW 24

(1) Housing of the filling machine (2) Hydraulic unit (3) Bottle support (4) Filling device (5) Filling tank with removable lid (6) Hydraulic operated support for fittings (7) Vacuum line to vacuum pump (8) Milk inlet pipe (9) Laminate for caps (10) Cap die (11) Sheet for diversion of laminate waste (12) Cap channel (13) Cap depositing (14) Closing device (15) Control button (16) Housing of capping machine (17) Turning disk for varidrive

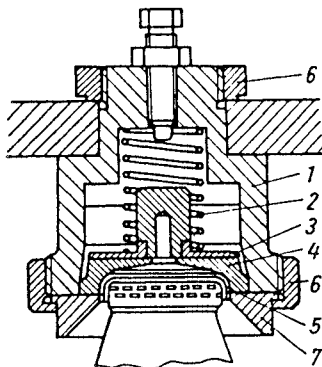


Figure 5./8 Cutaway of capping device

(1) Base (2) Pressure spring (3) Pressure plate (4) Rubber disk (5) Cap (6) Thread (7) Centering device

Caps are formed from a laminate in a press (10) (which is situated on top of the sealing device) with a die. A channel (12) leads the caps—sometimes marked with an expiration date—into the depositing device and laminate waste is diverted by an inclined sheet

(11). Closing elements (Figure 5./8) push the cap rim against the bottle mouth, thus fixing the cap. After one complete round in the capper, the bottle passes through an outlet star wheel onto a conveyor belt.

5.1.3.3. One-way container

Single-use sales units are called one-way containers (or lost containers). According to their size and shape they can be classified as single units, household units and bulk units.

Bulk units have a volume of 2–200 liters, e.g., bag-in-box, are destined for catering use, and are described in detail in 5.1.2.1. Household units are one-way containers with a volume of 1–5 liters. Both types of packaging are supposed to guarantee safe transport, protect the product, and handle easily. Individual units should have sufficient rigidity, easy discharge, resealability, and be used for drinking without auxiliary means. Portion packs are destined for instant consumption or utilization.

Other distinctions can be made as a function of the packing material (plastics such as polypropylene, polyvinylchloride, polystyrol; cardboard and paper made from sulfate cellulose, aluminum laminate). There are laminate pouches, paper-based packing material, plastic bottles and cups.

According to the microbiological status, we distinguish between a nonaseptic packing (where a certain level of microbiological contamination is not excluded) and an aseptic packing (which is germ free). The advantages of the one-way packing are:

- a) No costs for packing material returns, no investment, operating and maintenance costs for washing machines
- b) Complete or almost complete light protection
- c) Easy handling and transport space utilization due to low tare weight and favorable packing shapes
- d) Wide variability of shapes and volumes
- e) Lower temperature increase in larger packs during transport and storage
- f) Low noise level during filling
- g) No accident hazards (glass breakage)
- h) No deposit, no domestic cleaning and return to the trade

5.1.3.3.1. Laminate packaging

The most widely used geometric form is the pouch, and it is available as a household pack with 1 liter net volume. Because it is not rigid, an auxiliary tool (jug) is required if it is not immediately used. This pouch can be manufactured in two ways:

- a) The laminate tube is drawn off from a coil, and the laminate is cut to size. After application of the bottom seal, the packs are transferred to the filling devices, are filled and thereafter the top seal is applied.
- b) The laminate is drawn off a coil, passed over a forming shoulder and formed into a pouch; the vertical and horizontal bottom seals are applied, the pouch is filled, the upper seal is applied and the entire pouch is cut from the laminate.

Some machines have vacuum devices, which can remove air from the headspace of the filled bag.

Normally each filling machine is designed for a defined net volume. In many cases, several pouch filling lines are integrated in a processing line, which is automatically controlled (including all the auxiliary equipment).

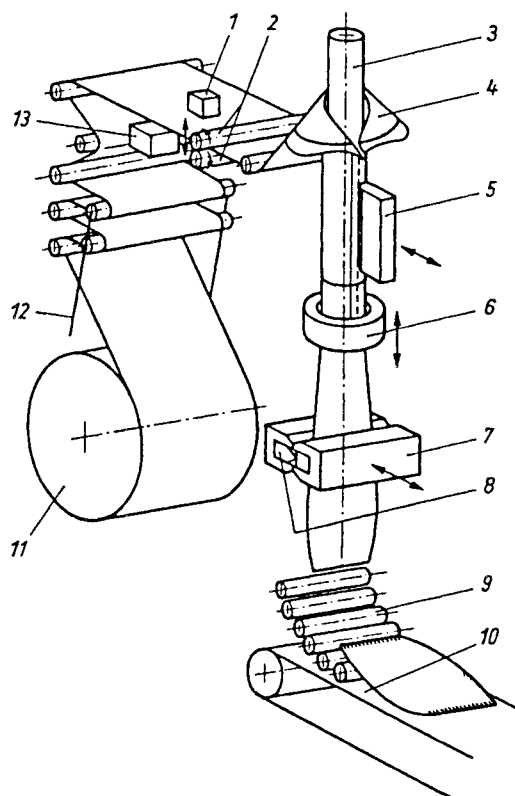


Figure 5./9 Tube filling and sealing machine type HM 3 (basic principle)

(1) Image centering device (2) Draw-off drums (3) Filling tube (4) Forming shoulder (5) Vertical sealing bar (6) Vacuum ring for the transport of the tube (7) Gripping device (8) Horizontal sealing bar and cutting device (9) Outlet conveyor (10) Transport conveyor (11) Laminate coil (12) Swing (13) Coding device

Pouch forming machine. It is the key element in a process line and controls the capacity. The working principle of the filling operation is shown in Figure 5./9. The laminate is drawn off from a coil (situated in the back) with a swing (12), draw-off rods (2) and a gripping ring. A coding device (13) continuously prints the expiration date. The forming shoulder (4) (in the upper part of the machine) forms the laminate into a pouch, its longitudinal overlap is sealed into the horizontal seal at a temperatures of approximately 160 °C. In parallel with this operation, a horizontal seal is made at temperatures of 185–190 °C, establishing the bottom seal and the top seal of the previously filled pouch. It is then cut off (separated). An air current cools the heated seal, causing the laminate to shrink slightly in these areas.

Filling is done through a buffer tank, dosing tank and filling tube, which is inserted into the pouch. The filled and sealed pouch is cut off and is transferred via conveyors to be packed into the transport crates.

5.1.3.3.2. Carton packaging

The basic raw material for this type of packing is sulfate cellulose in form of paper or cardboard, coated according to the requirements with plastic, wax and/or aluminum laminate. Figure 5./10 shows the possible structure of such packaging laminate, as it is used for aseptic filling. For nonaseptic filling, a simpler structure can be used.

The normal geometric shapes are shown in Figure 5./11. Net volumes are in the range of 10 ml (portion pack for coffee creamer) to 1 l, with the 0.5 and 1 l being the most widely used for household packs.

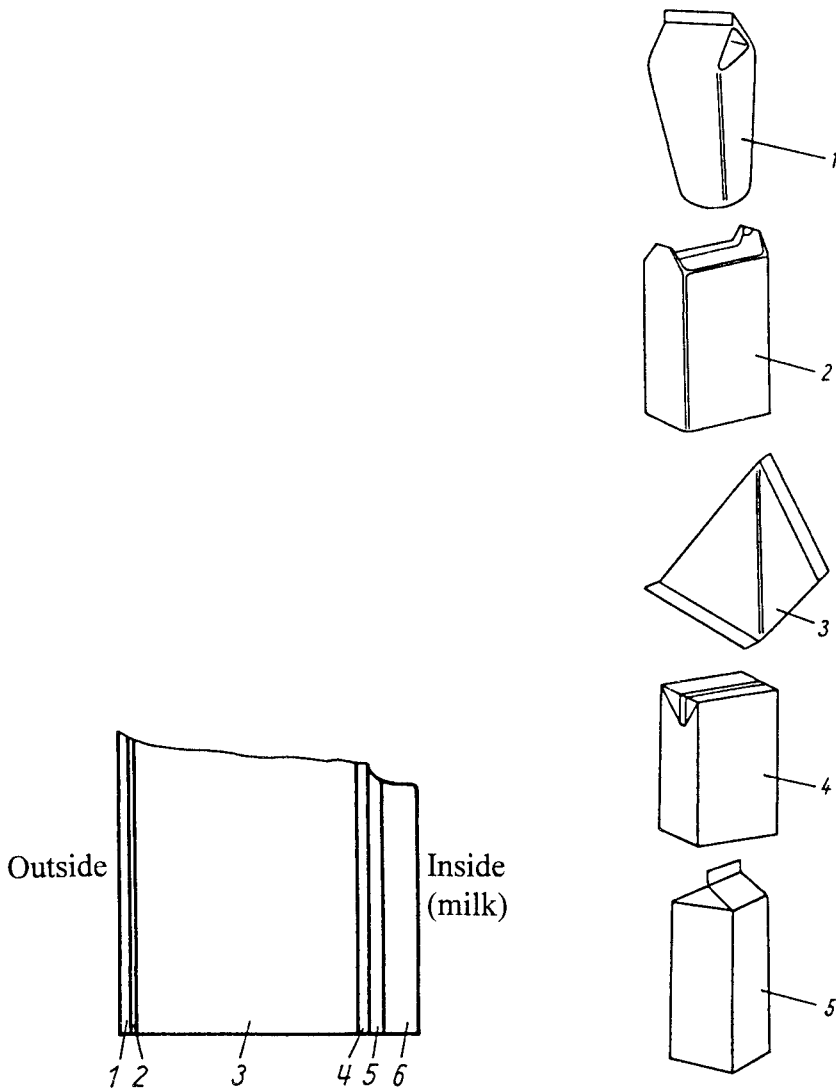


Figure 5./10 Packing material structure for aseptic filling

- (1) Polyethylene (PE) (2) Printing layer
(3) Cardboard (sulfate cellulose) (4) PE
(5) Aluminum (6) PE

Figure 5./11 Shapes of one-way containers (selection)

- (1) Cup type (2) Square box (3) Tetrahedron
(4) Square box ("Brik") (5) Gable-top

The tetrahedron pack has very high rigidity and can easily be used without any additional means. Stacking is a problem; therefore special baskets, crates or cardboard boxes have been developed. The manufacture of these tetrahedrons is shown in Figure 5./12. As

in the case of the pouch filling machines, several tetrahedron filling machines are integrated in a process line, as each machine has only one fixed volume.

Square boxes have basically the same characteristics as the tetrahedron shapes, but offer the additional advantage of good and variable stacking possibilities (Figure 5./13). Sales units can be made according to marketing requirements, and they form a “cooling block”; i.e., the temperature increases during storage and transport can be kept to a minimum.

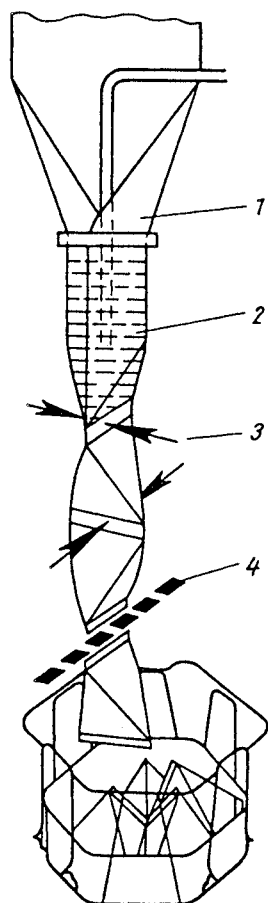


Figure 5./12 Manufacture of a “Tetrahedron Classic”

(1) Laminate is formed into a tube and is sealed under pressure and heat (2) Milk is injected by a tube below the liquid level (3) The tube is sealed by horizontal seals using pressure and heat (4) Packs are cut off and are placed into the transport crates

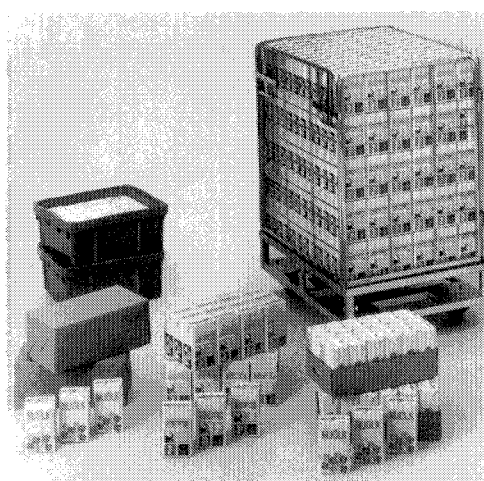


Figure 5./13 A selection of transport packs

5.1.3.3.3. Aseptic packaging

- Aseptic filling is the filling of a sterile product into a sterile pack under sterile or germ-reduced conditions.

In contrast to aseptic technology, classic sterilization technology is based on filling nonsterile products into nonsterile containers under nonsterile conditions, and then sterilizing the container. The advantage of aseptic filling (compared to sterilization technology) is mainly very high retention of organoleptic and nutritional food qualities as well as better economics. For aseptic filling the following requirements must be met:

- a) Presterilization of the product and maintaining sterile conditions during transfer and filling
- b) Presterilization of equipment parts in contact with the product as well as all pipelines for product, gas and air
- c) Maintaining sterility for all required areas including the atmosphere around the filling lines
- d) Sterilization of packing material or containers
- e) Utilization of germ-impermeable packing material or containers

Sterilization of the dairy products is achieved by ultrahigh heat treatment, it can be achieved to a certain degree also by ultrapasteurization (see Overview 4./4). Sterilization and maintaining sterile conditions in the installations are achieved by systems which are integrated in the filling lines. They are operated mainly with steam and hot air, but can also use chemical preservatives and combinations thereof.

Sterilization of the packing material is done mainly chemically, using peroxide and heat treatment. The sterilizing effect is achieved by the reduction of H_2O_2 into active oxygen. The ensuing heat treatment of the packing material serves to evaporate the residual hydrogen peroxide.

Various acids and/or gases are used for the sterilization of packing material during the aseptic filling of acidic products ($pH < 4.6$). For chemical sterilization of packing material two systems are mainly used:

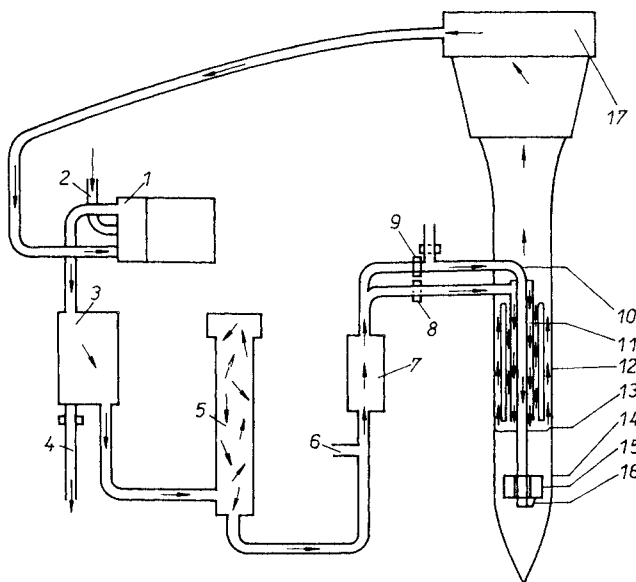
- a) Rolls—sterilization is done on the surface (surface directed toward the product) of the continuous laminate. After removal of the sterilization agent by heat, a continuous form-fill-seal of the pack is done under sterile conditions.
- b) Container—laminate is preformed into containers (cups, boxes), and the sterilization agent is sprayed into the container; the container is then sterilized and blown free with hot air. Thereafter the containers are filled and sealed under sterile conditions.

Chemical agents can be replaced by saturated steam (used as a sterilizing agent) in a temperature range > 130 °C. The limits are set by the amount of polystyrol and polyethylene in the packing material, as these components are sensitive to heat. Further, this type of sterilization can be used only for batch processes, and then only for cups. Sterile air is generated in auxiliary units, as shown in Figure 5./14.

Process lines. The filling machines are integrated in processing lines, linked to packing units. A complete processing line for aseptic brick packs is shown in Figure 5./15. The operation of such a line is described in detail hereafter.

Construction and operation of a Tetrabrik aseptic installation (Figure 5./16). Large-diameter coils are placed into the machines by hydraulic lifting devices (1). From the coil (2) the laminate is drawn off with a roller (3) and transferred over a rectangular roller (4) (which makes the laminate more flexible) to the stripping station (5). On one side of the laminate, a plastic strip is applied, which serves as a sealing agent during the vertical seal manufacture. This creates a very tight and dense seal. If the pack has a cut-open notch,

then perforation holes are applied in the perforation device (6). In the same way, the holes for the straws can be cut.



Picture 5./14 Generator for sterile air

(1) Compressor (2) Water inlet (3) Separator for air and water (4) Water discharge for air cooling in chiller (5) Air heater (up to 350 °C) (6) Partial flow of air to strip device and lateral seal heater of filling machine (7) Air cooler (8) Valve for air flow over fluid level (9) Valve for hot air flow for presterilization of the system (10) Product feed pipe (11) Sterile air pipe (12) Electro-tubular heating for packing material sterilization (13) Return flow of sterile air with incorporation of evaporated sterilization liquid (14) Fluid level on sealed pack (15) Flotation regulation device (16) Product throttle valve (17) Air collector for return flow to compressor

Using the sealing bar (7), the plastic strip is attached to one side of the laminate. The strip covers the notch or the straw opening completely. Coil (9) supplies the strip for the notch and is sealed onto the laminate with a sealing bar (10). Roll (10) controls the image centering device for the opening notch device, and roll (12) controls the proper transport of the laminate between the notch device and the other devices of the machine. This is necessary, because the opening notch device works on a given sequence, whereas the other functions of the installation work continuously. Roll (11) serves as the drive for the packing material laminate.

Sterilization of the packing material is done by passing the laminate through a hydrogen peroxide bath (13); thereafter the excess hydrogen peroxide is removed by squeegee rollers (14). The laminate is dried with an air current, exiting from a longitudinal gap (15), and another square roller makes the laminate more flexible. Roller (17) controls the image centering device.

The laminate is formed into a tube, and the filling tube (18) is inserted. The next step is the vertical sealing (19), followed by filling and then horizontal sealing (20). The entire operation of forming and sealing is shown in Figure 5./17. After the sealed packs are

cut off, they pass through the edge folding station, where the top and bottom edges are folded and sealed to the pack (22). A piston pushes the pack onto a conveyor belt, and then the packs are transferred to the packing stations.

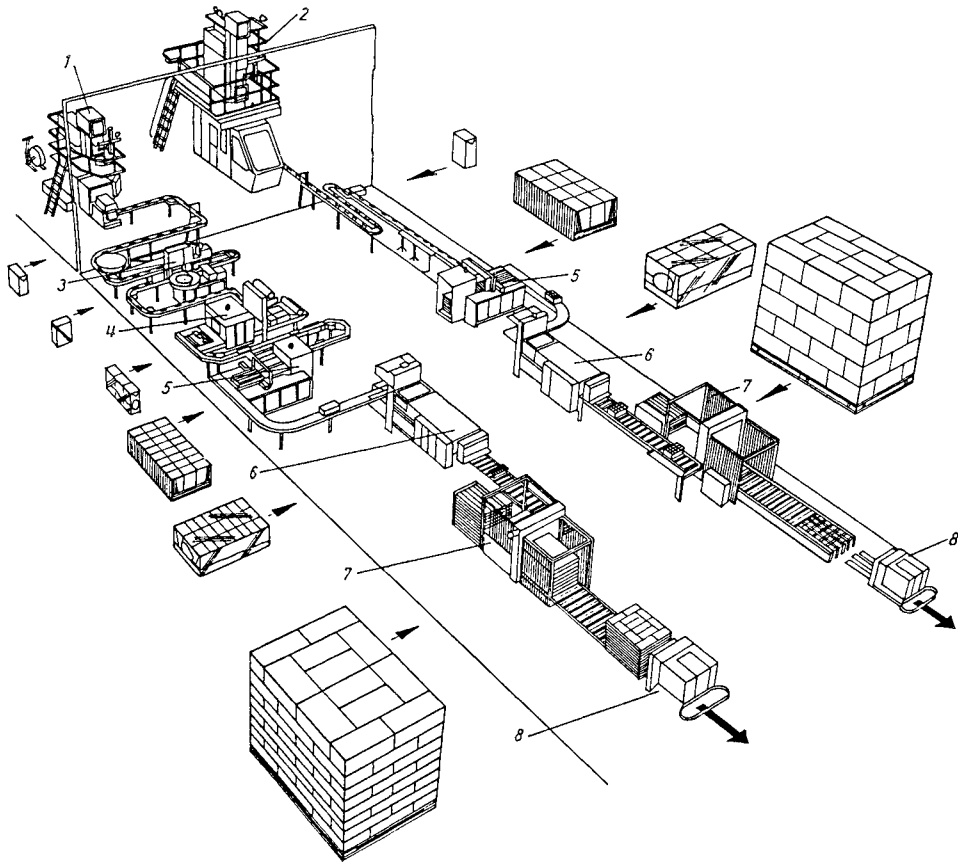


Figure 5.15 Example of an integrated process line for brik-shaped aseptic packing of various sizes

(1) Aseptic filling machine for packs with a net volume up to 0.25 l (2) Aseptic filling machine for packs with a net volume up to 1 l (3) Straw applicator (4) Shrink-wrap case packer for units up to three pieces (5) Infeed of individual or triple units into boxes (6) Shrink-wrap machine for transport unit (7) Palettizing of transport units (8) Transport device for pallets

5.1.3.3.4. Plastic bottles

This type of one-way containers is used mainly for the filling of sterilized milk, UHT products and infant food. The basic characteristics of these packs are:

- a) Very resistant to mechanical influences (low breakage risk)
- b) Resistant to temperatures $> 100\text{ }^{\circ}\text{C}$

- c) Can be used as a see-through pack or as a pack with complete light protection
- d) Can be manufactured in many shapes
- e) In situ extruded bottles are nearly sterile during filling

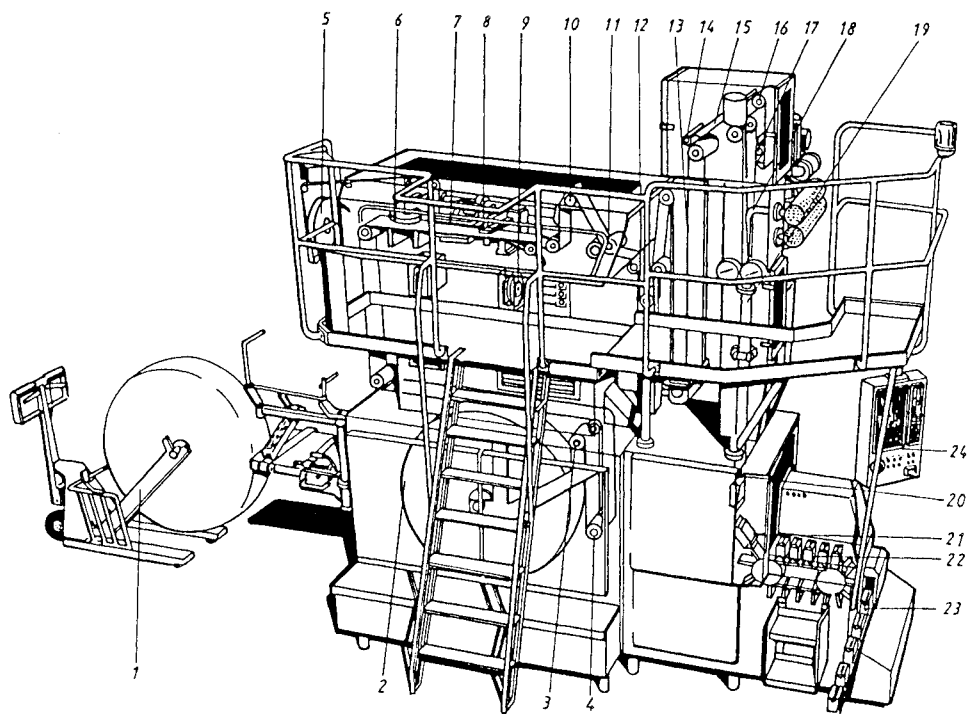


Figure 5./16 Design of a Tetrabrik aseptic filling machine type AB9; capacity 5.000 to 6.000 packs per hour; filling volumes 125 ml, 180 ml, 200 ml, 236.6 ml and 250 ml; energy 40 kW; compressed air consumption 05 m³/min at 6–7 bar; steam pressure 2.7–3.0 bar; water consumption for a 30 min cleaning cycle 150 l cold water and 150 l hot water at 70 °C; cooling water consumption 11 l/min at 20 °C

(1) Hydraulic jack for laminate coil (2) Laminate coil (3) Drive for laminate coil (4) Square roll (5) Strip applicator (6) Device for opening notch (7) Sealing bar for plastic strip (8) Sealing bar for notch (9) Coil for opening notch (10) Control of the image centering device (11) Drive roll (12) Adjustment roll (13) Hydrogen peroxide bath (14) Squeegee roller (15) Air current (16) Square roller (17) Image centering device (18) Product inlet (19) Sealing bar for vertical seal (20) Horizontal sealing bar (21) Transport to folding device (22) Folding device (23) Conveyor belt (24) Control panel

Materials used are polyethylene and polypropylene for one-way bottles, as well as polycarbonate and Lexan for premanufactured multiple-use bottles.

Process. The bottle is manufactured in extruders, where a plastic granulate is heated and the bottle is shaped by blowing air into the mold. Several molds can be combined, which increases the capacity of the installation. Filling and sealing can be done either directly in the blow mold or in separate filling and sealing machines, which are installed after the extruders and blow molding machines. In the first option, the closing is done by sealing the mouth of the bottle with the same material which is used for the bottle. When using

postextrusion filling and sealing machines, closing methods used are similar to glass bottle closures (crown caps, aluminum caps, pilferproof caps—these are disks made from plastic, aluminum or aluminum laminates which are placed on the bottle opening and are sealed with the opening).

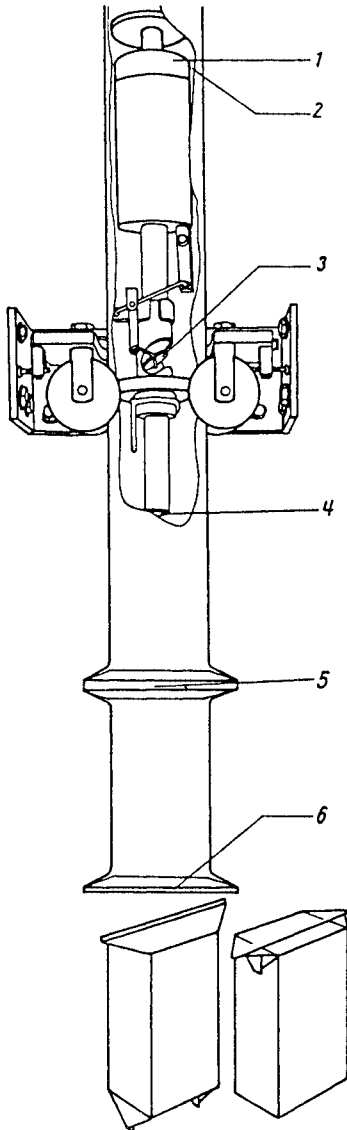


Figure 5./17 Laminate forming and level control in an aseptic filling machine as in Figure 5./16

(1) Stainless steel floating device (2) Liquid level (3) Throttling valve, linked to the floating device by a joint (4) Opening of the filling tube (5) Horizontal sealing (6) Cut-off of the pack and folding of the edges

Installations with in situ filling of the blown form have a very compact design and require less space than those with a separate filling and sealing installation. The sealed bottles are transported by conveyor belts to the packing installation, where they are placed into either plastic crates or different forms of cardboard boxes and are prepared for transport.

Design and operation of a blow-molding plant (Figure 5./18). The mold consists of four parts; two parts serve in the manufacture of the body of the bottle, and two are used to manufacture the neck and top of the bottle.

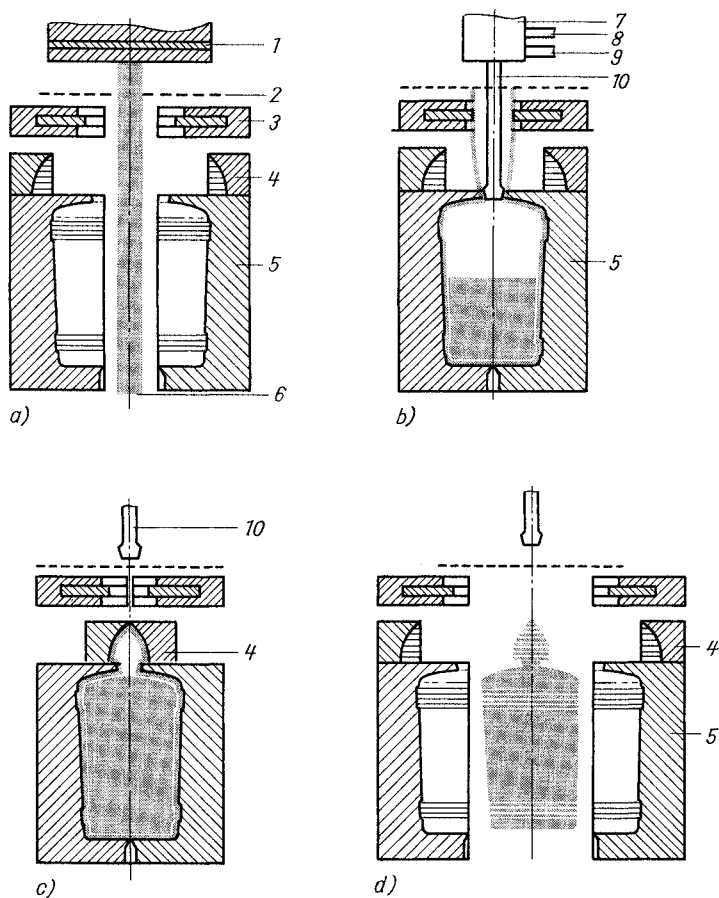


Figure 5./18 Operation of a machine for forming, filling and sealing of plastic bottles, type "bottle pack 301"

(1) Blowing mold (2) Cutting device (3) Holding grip (4) Upper forming parts (5) Lower forming parts (6) Plastic tube (7) Pin guidance (8) Filling tube (9) Air evacuation channel (10) Filling pin

A plastic granulate—from a feeding device—is extruded and formed into a tube (6). After reaching the required length, the mold surrounds the tube, which is then centered by a holding clamp (3) and is cut off by a cutting device (2) from the molding head (1) (Figure 5./18a).

The closed mold is transferred into the next position for forming, filling and sealing of the bottle. A pin (10) is inserted into the neck of the lower mold (5). A short jet of compressed air blows up the hot tube, so that it fills the cavity of the mold. At the same time, the exact quantity of the product to be filled (metered by a dosing device) is transferred via the filling tube (7) into the bottle. The air is removed via channel (9) (Figure 5./18b). During the filling of the product, the hot plastic body solidifies, the forming pin (10) moves back into its original position, and the two upper forming parts are closed. During this operation, the bottle is sealed while simultaneously forming a closing knob (Figure

5./18c). The four forming parts (4) and (5) are opened; the bottle drops from the form (Figure 5./18d) and is transferred to the packing station.

5.1.4. Labeling of fresh milk

All food must be labeled in order to provide clear information to the consumer for certain products and to avoid misleading. At the same time, the products are properly classified. Further specific requirements regarding advertising and nutritional labeling must be complied with. The following requirements—as shown in Figure 5./19—must be shown in a legible manner in a prominent place for packaged milk:

- a) Denomination—e.g., whole milk, partially skimmed or fat-reduced milk, skim milk.
- b) Identification marks—in an oval field in the upper part in capital letters indicates the country of manufacture or distribution, in the center part is the veterinary control number of the plant, and in the lower part is the acronym for the economic area e.g., EEC.
- c) Name and address of the manufacturer, plant or distributor.
- d) Expiration date—for pasteurized whole milk, partially skimmed and skim milk use “at 10 °C best before ...” For milk with a shelf life of ≤ 3 months the year can be suppressed, with a shelf life of > 3 months, the day can be suppressed, for products with a shelf life of > 18 months, the day and the month can be suppressed if the expiration date is given as “minimum shelf-stable until end” The minimum shelf life date is not the same as the expiration date, last consumption or sales date; it is more a warranty indication from the manufacturer.
- e) Type of heat treatment—e.g., pasteurized, UHT, sterilized.
- f) Net volume.
- g) Fat content—whole milk with a natural fat content “minimum 3.5%,” whole milk with a standardized fat content and fat-reduced milk “... % fat content.” For skim milk an indication of the fat content is not required.
- h) Homogenization—use the word “homogenized” if homogenization has taken place.
- i) List of ingredients—for partially skimmed milk or skim milk indicate whether water soluble or processed milk proteins have been added.

For bulk milk, indications regarding the type, fat content and type of heat treatment must be shown on a label. For raw milk direct from the farm, the indication “Raw Milk” must be placed prominently for control purposes. Further, it must be indicated prominently that raw milk must be boiled before consumption.

The preceding indications are valid for all kinds of dairy products; however, product-specific modifications do apply. A further discussion of labeling will not be given in other product-specific sections of this book, and we refer to this general section.

5.1.5. Storage and distribution of fresh milk

Market milk as well as all other dairy products should be transferred immediately after packing to suitable storage facilities, and they stay there until further distribution takes place.

- Products must be stored at ≤ 10 °C, if they are susceptible to rapid quality deterioration.
- Pasteurized milk must be stored and transported at ≤ 6 °C.

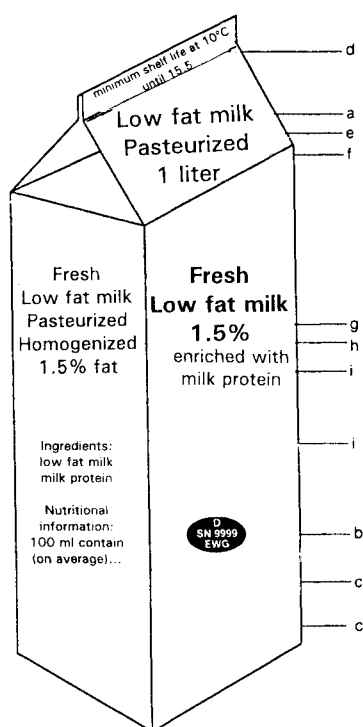


Figure 5./19 Labeling of market milk

Products should be stored in such a way that the largest possible “block” is created, which reduces the absorption of ambient heat. In addition, the storage space should be utilized in the best possible way.

- Doors to the cold storage should remain closed as long as possible.

Vehicles and containers for the transport of milk and dairy products must be designed and equipped in such a way as to maintain the temperature during the entire transport as low as possible. For cooled products the best vehicles are those which are closed, insulated and have a refrigeration facility.

During the transport of heat-treated milk in small containers or churns, sufficient protection against any dirt and seasonal influences must be provided. This means that the truck platform must at least be covered with sheets. Further, the truck platform needs to be cleaned and disinfected easily.

Good logistics, i.e., efficient and well-managed distribution, requires good planning of all operations including proper administration and paper documentation. All personnel who are employed in the transport need to have a health certificate.

5.1.6. Quality evaluation of fresh milk

For the different types of milk the following quality criteria are applied:

- Raw milk
 - TPC 30 °C/72 h per ml $\leq 50,000$
 - *Staph. aureus* per ml: m = 100, M = 500, N = 5, c = 2
 - *Salmonella*: absent in 25 g, n = 5, c = 0

- Pathogens: absent
- b) Pasteurized milk
 - TPC at 21 °C/25h after 5-day storage at 6 °C per ml: $m = 50,000$, $M = 500,000$, $n = 5$, $c = 1$
 - Coliform bacteria per ml: $m = 0$, $M = 5$, $n = 5$, $c = 1$
 - Pathogenes: absent in 25 g, $m = 0$, $M = 0$, $n = 5$, $c = 0$
 - Peroxidase: positive
 - Phosphatase: negative
 - Freezing point: ≤ -0.515 °C
- c) Sterilized milk or UHT milk after a 5-day incubation at 30 °C
 - TPC at 30 °C/72 h per 0.1 ml ≤ 10
 - organoleptic evaluation: normal, no deviations
 - antibiotics or other pharmacological inhibitors/reagents: absent
 - Freezing point: ≤ -0.515 °C

In pasteurized milk, the lactulose level should not exceed 400 mg/kg. Sterilized milk has to react negatively to the Aschaffenburg opacity test.

Additional criteria can be established by the states (Länder), such as SH value, pH, specific density, fat content, alcohol test and filter test. All marketed milk is subjected to an organoleptic test covering taste, smell and appearance.

5.2. Milk drinks

5.2.1. Terms and definitions

- Milk drinks are products ready for consumption, made from milk with differing fat contents and additions such as sugar, cocoa, fruit concentrates, coffee, flavors and/or other food ingredients, which are homogeneously mixed and contribute to flavor and taste. A level of 30% of additives should not be exceeded in the finished product.

Milk drinks are part of “dairy-based products.” The various types can be manufactured on the basis of whole milk (3.5% fat), fat-reduced milk (1.5–1.8% fat) or skim milk ($\leq 0.3\%$ fat). They can be commercialized in the form of pasteurized, UHT or sterilized products.

Apart from taste-influencing additives, other ingredients, e.g., stabilizers, are added, which contribute to a homogeneous structure and distribution of the additives. Basic products can be enriched with milk proteins, or whey and ultrafiltrate (permeate) are added to refreshing beverages.

Milk drinks are the result of consumer demand for an increased variety in taste. Children can be enticed to consume more milk, and this will also help in school milk programs.

Initially, the preparation of these products was limited to catering and households. The steadily increasing demand has resulted in a significant marketshare for these dairy products.

5.2.2. Food additives

Food additives are indispensable (even characteristic) for milk drinks and other dairy products. Therefore some basic statements will be made here about this class of items. A

few very important ones will be described in detail.

- Food additives must be considered as food but are not consumed as such. They are added intentionally to food during its manufacture at any given stage of production, filling or packing for reasons of technology or organoleptics. These additives become part of the food, in order to provide some very specific and precisely defined characteristics such as taste, appearance, consistency, shelf life and others.

Although food additives are not food as such, they are part of food to a varying extent. A codex has been established by the FAO/WHO Codex Alimentarius commission for using them properly, which reads basically as follows:

- The utilization of food additives is justified only in cases in which they are indispensable for technological reasons. Only the smallest possible amount should be used, and there should be no health hazard involved for the consumer.

From a legal point of view, food additives are equal to food and are monitored for their level of toxicological contamination risk. Food additives may contain not more than 3 mg/kg arsenic, 10 mg/kg lead, 1 mg/kg cadmium, 25 mg/kg copper, 0.5 mg/kg mercury and 25 mg/kg zinc. Further, the FAO/WHO has established so-called ADI values (acceptable daily intake)¹ which limit the presence of these components in food. However, these values include “additives” and components which are added unintentionally to food during its manufacture. Here we include “technical additives” and “contaminants.”

- Technical additives, excluding machines and instruments, are used during the production of raw material and processing of foods and their ingredients for certain technological reasons, so unintentional and unavoidable residues or derivatives (e.g., solvents, filter aids) can remain in the finished product. These residues should not pose any health hazard and should not propagate in the finished product.
- Contaminants are products which are not added intentionally to the food, but are present as a residue in food during the preparation, manufacture and filling/packing or due to environmental pollution.

Classification. A classification can be done according to their type or their function. The various types of ingredients or groups of ingredients have multiple reactions. Some components can have a preserving effect, color-modifying effect, or taste and flavor modifying effect. Following are the most prevalent types of food additives, which are used in dairy technology as well as their function:

- a) Additives for modifying the consistency or achieving and maintaining a defined texture (viscosity-increasing ingredients, binding agents, stabilizers, gelling agents, emulsifiers)
- b) Additives for the decomposition of protein (enzymes) and fats (molds)
- c) Additives to increase or maintain shelf life (preserving agents, antioxidants)
- d) Additives to modify the appearance (colorants)
- e) Additives to modify taste and flavor (natural or nature-identical flavors)
- f) Additives to increase the nutritional value (provitamins, vitamins, amino acids, yeast products, protein concentrates and hydrolyzates, modified sugars)

¹ ADI value (acceptable daily intake) is the acceptable daily quantity of an ingested substance in mg and per kg body weight, which does not constitute a health hazard if ingested during the entire life span based on current scientific knowledge.

- g) Additives for foaming and gassing (air, nitrogen, carbon dioxide, ethylene oxide)
- h) Additives for water treatment

Hydrocolloids. Based on their chemical-physical class, hydrocolloids are the most widely used additives; they are macromolecular and hydrophilic, are soluble in water or aqueous phases, can be dispersed and absorb water, and result in highly viscous solutions, suspensions or gels at very low concentrations. Hydrocolloids are used for effects as mentioned under a). These agents can be described as follows:

- Binding agents are ingredients which serve to compound or bond together. Here we find thickening agents, stabilizers and emulsifiers.
- Thickening agents (swelling agents) are macromolecular hydrocolloids, which have hydrophilic characteristics and form—even at low concentrations in aqueous solutions—highly viscous compounds, suspensions, colloidal solutions or gels.
- Stabilizers are ingredients with molecular masses of 1500, which create interfaces or electrical charges and operate as protective colloids. They are fat insoluble, form colloidal distributions in foods and inhibit the agglomeration of fine particles.
- Emulsifiers reduce the surface tension between individual phases. These oil- or wax-like substances can create finely dispersed systems from initially nonmixable phases. They have hydrophobic and hydrophilic characteristics.
- Compounds with indirect emulsifying and/or stabilizing characteristics modify ingredients such as proteins in such a way that they become emulsifiers (phosphate compounds).

Nearly all technically or technologically important hydrocolloids have a plant or animal origin. Here we mention only the most important ones, based on their origins:

- a) Pectins; different high- and low-esterified polysaccharides, made mostly from apple and citrus residues
- b) Polysaccharides and leguminous seeds (galactomannanes); carob flour
- c) Plant extracts; extracts such as caoutchouc, gum arabic, gum ghatti and others
- d) Seaweed extracts from red algae such as agar-agar, carrageenan, furcellaran or from brown algae such as alginate
- e) Starch and starch derivatives; amylopectin and amylose, potato, rice and corn starch and others
- f) Semisynthetic cellulose derivatives; cellulose alkyl ether, sodium carboxymethyl cellulose
- g) Fermentation polysaccharides from microbiological reactions; xanthan
- h) Animal origin; gelatin, caseinate, coprecipitates

Key criteria for the selection of the hydrocolloids are functionality and price. Gelatin is more widely used than other hydrocolloids in the dairy industry for price reasons and its functionality and will be described in more detail hereafter.

Gelatin. Gelatin is a hydrocolloid of animal origin, and is obtained either from pork hide as type A by acid processing or from beef hide or bones as type B by an alkaline process. It consists of:

Protein	84–86%
Moisture	8–12%
Minerals	< 2.5%

Gelatin is used in dairy products for an increase in viscosity and product stabilization, but mainly for the formation of gels. Here surface tension between the product phases is further reduced and water absorption is increased.

The main criterion is the strength of the gel, which is measured as penetration and is indicated in Bloom values. Here we distinguish between:

- a) Gelatin with a low Bloom value < 120 Bloom
- b) Gelatin with a medium Bloom value 120–200 Bloom
- c) Gelatin with a high Bloom value > 200 Bloom

The isoelectric point is of technical importance; it is in the range pH 8.0–9.0 for type A and pH 4.8–5.4 for type B. The product pH and the gelatin pH should preferably be in different ranges; for milk products this means that type A is mostly utilized. Gelatin is commercialized in powder or granulate form, also with instant properties, having particle sizes of 0.1–10 mm.

For utilization during the manufacturing process, an aqueous solution is prepared. Powder is dissolved into 5–10 times the amount of hot water (about 60 °C). A preswelling can also be done in hot water, and the solution is then brought up to the required temperature.

- Gelatin solutions must be used in the temperature range of 55–65 °C. Prepared solutions must be used immediately.

Gelatin hydrolyzates are made from gelatin and have lost their gelling characteristic due to enzymatic modification of the collagen molecules. They are cold-water soluble and free from bitter peptides, purine, cholesterol and saturated fatty acids. Gelatin hydrolyzates serve for color improvement, taste enhancement, and especially foam stabilization and have a protective colloid function.

Fruit preparations

- Fruit preparations are products that may be used in the manufacture of dairy products. They consist of fruits, fruit components and sugars, but also contain extracts, flavors, coloring agents, binding agents and food acids and have been preserved by either heat treatment or chemical preservation.

The fruit content of these preparations is a minimum of 35%, for raspberry-blackberry blends, red currants, gooseberries, plums and pineapple it is a minimum of 30%, for bananas and black currants it is a minimum of 25%. For coloring purposes foods such as cherry juice, red beet juice and others are used in such a quantity that the typical color develops in the finished dairy product. For stabilization, gelling and thickening agents such as starch, gelatin and other ingredients are used.

Fat replacement/fat substitutes. The purpose of these ingredients is mainly to reduce the fat and energy content by replacing fat with these low-energy ingredients. At the same time these ingredients should have the same technological, rheological and organoleptic characteristics as fats (or should be close to them) and should comply with nutritional, legal and economic requirements. Currently the following groups of fat substitutes are known:

- a) Modified starches, such as “Maltrin 040 maltodextrin” (hydrolyzed cornstarch) or “Snowflake” (enzymatically hydrolyzed potato starch). These ingredients are neutral in taste, water absorbing and influence the texture by thickening and gel formation.
- b) Saccharose polyesters, e.g., “Olestra,” which is a molecular mix of hexa-, hepta- and octaesters of saccharose with long-chain fatty acids. These ingredients have a fat-like consistency, are heat resistant, and have a caloric value of 0, as they are not broken down by bacteria or enzymes in the gastrointestinal tract. The toxicological safety still must be proved in long-term tests.
- c) Proteins, such as “Simplese 100” (heat coagulated under pressure and microparticle-sized whey proteins) or “Lacprodan 80” (ultrafiltrated whey protein concentrate).

Fat substitutes as under c) are of great interest in dairy technology. Apart from their primary function whey proteins have a wide area of application.

Further, “Simplese 100” has a very favorable final pH of 6.0–6.5 in practical applications, and the particle size can be reduced by micromilling to 0.5–2.5 μ m. In this range of particle size, which is close to that of homogenized fat globules, a creamy structure is achieved in foods, so that organoleptic perceptions “creamy” and “soft” can be noticed, similar to those associated with high-quality fat.

Food colorants. Among the additives we also find the food colorants.

- Food colorants are ingredients, which are used for coloring foods or for the manufacture of food colorants.
- Food colorants are blends or preparations of food colorants destined for coloring of foods. They can contain carriers or solvents.

Coloring of foods can be done only with the following groups of colorants:

- a) Natural organic food colorants
- b) Artificial organic food colorants
- c) Artificial organic food colorants for special applications
- d) Artificial pigments for special applications

Overview 5./2 Natural and artificial colorants suited for dairy products

Dairy product	Natural organic colorant	Artificial organic colorant
Cheese or cheese rind	Annatto (Norbixin orange) L-orange 7G and 8 Orseilles (red) Canthaxanthin (yellow) Saffron	Chryosin (yellow, for cheeserind) Lithorubin (cheese wax)
Melted cheese	Red beet (betanin) Curcuma (orange)	
Yogurt, fresh cheese	Red beet (betanin) Carotenoid (orange)	
Butter, margarine	Annatto (Bixin, Orleans) Carotenoid (orange) α -, β -, γ -Carotene (yellow) Lutein (orange)	

The coloring of food with natural food colorants is permitted in principle. Cheese and other dairy products can be colored with these ingredients without any basic limitation. However, basic food stuff should not be colored.

Coloring with artificial food colorants is permitted by legislation only for defined food groups, and these foods have to carry the label “colored.” Milk drinks, fruit yogurts or quarg preparations and ice cream preparations can be colored with these compounds, and the cheese surface can be labeled with them.

Colorants as mentioned under c) and d) are not permitted for coloring dairy products. It is a basic principle, that the coloring of food should be done with the minimum amount of colorant necessary. Further, FAO/WHO has established ADI values. The coloring of food should not indicate a quality level which does not exist. Overview 5./2 shows food colors, which can be used in dairy products.

Flavors and extracts. Flavors (also termed aromas) and extracts (to a limited extent) are widely used during the manufacture of milk beverages, while complying with legal limitations.

- Flavors are chemical compounds, which have a specific taste or smell. They impart (either individually or in blends) a defined taste or smell to food, excluding a simple sweet, acidic or salty taste.
- Extracts (aromas) are products, which contain aromas in concentrated form and are prepared with food or additives, in order to impart a characteristic flavor and/or taste to food.

Among flavors we distinguish:

- a) Natural flavors—made from plant or animal raw materials, using physical methods
- b) Nature-identical flavors—identical in their chemical composition and structure, but manufactured synthetically
- c) Artificial flavors—manufactured synthetically, not nature-identical

As a function of their chemical composition and the method of manufacturing, flavors can be classified further into seasoning, oleoresins (compounds bound to fats/oils), oils, concentrated fruits and juices, flavors which are generated during manufacture, e.g., roasted products, fermentation products and artificial flavors.

Food which has been manufactured by using those flavors and aromas, must be labeled according to the current legislation. Essences are also called “flavor concentrates, concentrated preparations” or “preparations ready to use.” The flavor ingredients can be bound to carriers (salt, lactose, starch) or dissolved in liquid (alcohol, water).

Gases. Gases are used as additives for whipping purposes or as a protection against microbial spoilage. Air is mainly used for whipping purposes or to increase volume for cream products; in most cases ambient air is incorporated into the product. Nitrogen is used mainly as a compressed gas in cream spray cans. Carbon dioxide, mostly used in combination with nitrogen, is used in the following applications:

- a) Inert gas packing of yogurt, quarg and dessert products
- b) Inert gas for cheese products, e.g., cheese or cheese morsels
- c) Inert gas for milk powder filling

When CO₂ is used as an inert gas, a germ-inhibiting atmosphere is created in the head-space of the pack, limiting microbially caused product changes. The gas mixture (95% CO₂ and 5% N₂) is injected into a pack with nozzles, and replaces the lighter air (50% lighter than the gas mixture).

5.2.3. Milk cocoa beverages

5.2.3.1. Terms and additives

Dairy-based products with additions of cocoa or chocolate are the most widely known and accepted milk drinks.

- Cocoa or chocolate milk drinks are dairy-based products, which are manufactured from heat-treated milk with the addition of cocoa powder and sugar and eventually stabilizers. After adding the powders, the product is heat treated with an accepted process, cooled and filled.

Standard products are made from whole milk (3.5% fat content), fat-reduced milk (1.5–1.8% fat) or skim milk and are labeled in accordance with the heat-treatment process and the powder quality (e.g., pasteurized cocoa milk, UHT chocolate milk, sterilized chocolate milk)

Additives. Additives are the different kinds of cocoa or chocolate powder which are used in the manufacture of the milk drinks.

These powders are obtained from the press cake of the cocoa beans, where the fat or cocoa butter has been extracted by pressing to different degrees. A product can be obtained which has a high to a low fat level with a fat content of $\leq 10\%$. The particle size of the powder is in the range of 10–30 μm , and the pH is in the range of 5–7. Sugar (saccharose) can be added to cocoa powder to a level of up to 65%. Other additives can be used such as vanilla, lecithin or other natural ingredients.

This powder is directly soluble in milk to a level of 20–30%. Cocoa milk is therefore a more or less stable suspension; a part of the powder slowly settles on the bottom of the pack (due to the higher specific gravity) and is redistributed by shaking. Homogeneous distribution of the additives is a prerequisite for good taste.

By adding 1–2% of a stabilizer (= 0.02–0.03% in the finished product), the viscosity of the cocoa milk is slightly increased and the cocoa particles remain suspended. The choice of the stabilizer depends on the selected heat treatment. For pasteurized cocoa milk, starch, gelatin or alginates are used; for UHT products mainly carrageenan is used, and for sterilized products cellulose products, e.g., carboxymethyl cellulose (about 0.2%) is used. For taste enhancement, additional natural or artificial flavors can be added.

Formulas. Per liter of milk about 12–15 g of cocoa powder and 30–45 g of sugar (saccharose) is added. The formulas are made according to powder quality, taste of the product and economics.

When calculating the quantities, the different densities of milk and cocoa powder as well as the different quantities (volumes in liters for milk and mass in kg for powders) must be considered. When adding 50 kg of sweetened cocoa powder to 1000 l of milk, we obtain 1019 liters of finished product.

5.2.3.2. Process technology

Preparation of the premixes. It is advantageous for good rehydration of the powder particles and simultaneously improved dispersibility to prepare a premix. This is the case when no or only small amounts of stabilizers are used.

Preparation of the cocoa milk. For small quantities (about 1000 l), small vessels with

efficient stirrers are used; for larger quantities tanks are used. In the first case, the entire preparation takes place in the vessel. When using tanks, a circuit is made consisting of a pump and a heat exchanger for heating and cooling.

Process. The milk is preheated to about 40 °C, and the premix is added. A homogeneous distribution is achieved by a vigorous stirring in the blending vessel or by pumping through the circuit. After extensive mixing, a heat treatment takes place using the selected heat treatment process. The cooling and filling process is selected as a function of the heat treatment process. Pasteurized products are cooled to 4 °C, and are filled into bottles or one-way containers. UHT products are cooled to 20 °C and are filled aseptically. For sterilized products, sterilization takes place after the filling process.

Quality evaluation. The following criteria are used in the evaluation of chocolate milk drinks:

Appearance (color), taste, flavor, consistency, coliform bacteria, total plate count, dispersibility of an eventual sediment, fat content, pH value and for UHT products a shelf life test after 6 weeks.

5.2.4. Milk with fruits

Apart from cocoa-based milk drinks other drinks are prepared using fruit preparations, flavors and essences. We further find other flavor variants such as “caramel.”

The technology is similar to that used in the manufacture of chocolate milk; however, some characteristics of the fruit preparation (e.g., heat sensitivity, pH value) must be considered. These dairy products can be manufactured as pasteurized, UHT processed or sterilized products.

5.3. Cream products

5.3.1. Terms and categories

- Cream products are products that are enriched to a varying degree with milk fat; they are nonacidified, acidified, whipped and may or may not have additives.

In Germany the words “Sahne” and “Rahm” (in English “cream”) are synonyms. The choice of words depends on the colloquial language and sometimes on the terms used in the guidelines.

- Cream is made by separating skim milk from whole milk, resulting in a fat-in-water emulsion enriched with milk fat, which has been processed by an accepted heat-treatment process. It is sometimes homogenized and eventually acidified.

Cream products are classified according to the application, the manufacturing process and the fat content. For products with a fat content of $\geq 10\%$ the term “cream” is modified by additional words such as “coffee cream” or “sour cream.” According to FAO standards, the following classification is made according to the fat content:

Cream	18–26% fat content
Light cream (or cream with additional terms, e.g., coffee cream)	> 10%

Whipping cream	> 28%
Heavy cream	> 35%
Double cream	> 45%

In Germany two standard products are known:

- a) Coffee cream $\geq 10\%$ fat content
- b) Whipping cream $\geq 35\%$ fat content

Other types of cream are “sour cream” (30%), “sweet cream” (28%), “cake cream” (36%), “butter cream” (30–45%), plastified cream for ice cream manufacture (60–75%). The increasing fat content changes the percentages of all components. Cream with a fat content of 30% has the following composition:

Fat		30%
Water		64%
Serum fat-free dry matter	Protein	2.4%
	Lactose	3.5%
	Minerals	0.4%

In addition, vitamins, enzymes, trace elements and acids are present in cream.

5.3.2. Whipping cream

5.3.2.1. Terms and requirements

Whipping cream is one of the food foams. Due to its taste and its multiple applications in decorating and refining of food it is widely accepted.

Whipping cream can be differentiated into the nonwhipped product—as manufactured in the dairy and then distributed—and the whipped cream. The cream is usually whipped immediately prior to consumption, either by the consumer or in the catering outlets (restaurants, bakeries and others). The basic requirements for this product are:

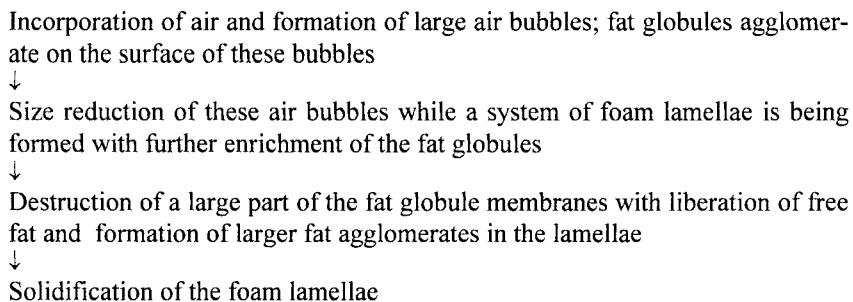
- a) Good whippability of the nonwhipped cream during storage.
- b) Whippability, i.e., short beating time and a volume increase of at least 80%, mostly 100–150%.
- c) Good foam stability and firmness of the foam—a defined weight of 100 g with defined dimensions should not penetrate more than 3 cm within 10 seconds.
- d) Low serum formation; i.e., a cube of whipped cream with 6 cm length/width/depth should not exude serum after 1 hour at 18 °C and should exude a maximum of 1 ml after 2 hours of storage.

5.3.2.2. Factors for whippability

Whipping of liquids is achieved mainly by strong mechanical treatment (whipping, blending, stirring). Foam formation is mainly based on the effect that in the boundary layers of the phases, liquid and air molecules are enriched due to a boundary layer activity and therefore stabilize the boundary layers.

Liquids which are suitable for foam formation have very low surface tension and can form membranes. The incorporation of air (or other suitable gases) into such liquids creates gas bubbles, which are separated from the liquid by a thin membrane. In the foam, bubble membranes are creating foam lamellae, which consist of a thin liquid layer, having

a boundary layer active substance that is active on both sides. The following sequence of events can be assumed to take place during the whipping of cream:



The stability of the foam depends very much on the firmness of the foam lamellae. This depends on both the boundary-layer active monomolecular substance and the rheological properties of the interlaminar liquids. Two basic mechanisms can reduce the foam stability or result in its destruction:

- a) Rapid outflow of the inner liquid and therefore breaking of the lamellae
- b) Gas diffusion through the liquid lamellae

In order to obtain sufficiently stable whipped cream, the following requirements can be derived from the above relationships:

- a) Standardize to a minimum fat content ($\geq 30\%$) in order to incorporate sufficient fat as a stabilizing substance into the lamellae.
- b) Maintain a product temperature of $< 10\text{ }^{\circ}\text{C}$ for fat stabilization and viscosity increase.
- c) Homogenize and improve the distribution of the fat in the lamellae.
- d) Increase viscosity of the proteins by reduced acidification or aging (ripening) of the cream.
- e) Improve the boundary layer activity while simultaneously increasing the viscosity with suitable additives.

If the quality standards permit and by using proper additives, the whippability and foam stability can be improved, and the fat content can be reduced to a level of 20%.

Caseinate (3–6%) is suitable for the improvement of the whippability and fat reduction; at a pH of < 5.0 it tends to flocculate. Whey proteins and milk coprecipitates (1–3%) are also well suited. In order to improve the foam stability, starch (3–4%), agar-agar (0.1–0.5%), carrageenan (0.015–0.1%) and others can be used. Additives which have both functions are gelatin (1–4%, at 20–25 $^{\circ}\text{C}$ and pH 4–7), or combinations of additives such as caseinate-gelatin blend with addition of 5–10% (on the basis of gelatin) in order to control the solidification temperature, a sprayed protein-fat powder (45% lactalbumin, 55% higher melting milkfat fraction, melting point 45 $^{\circ}\text{C}$) or blends of carrageenan with a protein-fat powder. These must be added before the heat treatment.

The cream can also be foamed by aerosols (air or gas quantities in which finely distributed liquid or solid particles are suspended). For this, cream is filled into a hermetically sealed can that is prefilled with an inert gas (nitrogen), which serves as a compressed gas and does not react with the product. Further, this prohibits a microbial spoilage, as germs cannot grow in this environment (or grow at a reduced rate). Aerosol foams

normally have reduced foam stability compared to foams made with air, but this can be compensated with stabilizers.

5.3.2.3. Process

A possible technology for the manufacture of nonwhipped cream in dairies is shown in Overview 5./3.

Cream preparation and fat standardization. Standard quality requirements for raw milk must be applied when manufacturing whipping cream. A special point is the fatty acid composition, which depends on the feed situation. Milk fat with a majority of saturated fatty acids, i.e., high melting point and a low iodine number (so-called winter cream), results in a firmer foam than a softer fat. Fat standardization is done in the separator in the same way as for market milk. Minor modifications can be made by adding whole milk or cream with a higher fat content. Fat corrections with skim milk result in reduced whippability and foam stability. These decisive quality criteria are improving with increasing fat content (> 30%), with 35% being the optimum.

Acidification/ripening. Whippability depends on both the characteristics of the membrane of the fat globules and the state of hydration¹ of the serum protein. Favorable conditions for foaming of the proteins exist at a pH of 6.4–6.2. To set the pH of the cream, butter cultures can be added (0.5–2%), followed by ripening at 10–15 °C, until the preset pH has been reached. The objective of the ripening is to achieve good fat crystallization or fat hardening. Total ripening time (before and after filling/packing) should be a minimum of 1–2 days at temperatures < 10 °C.

Homogenization. In general, homogenization improves foam stability and avoids the creaming of the fat, which is an absolute requirement for UHT and sterilized cream with their longer shelf life. Experience has shown that a single-stage homogenization leads to earlier gelation of the product, due to the inherent and additional viscosity caused by the agglomeration of fat globules. A two-stage homogenization is preferable with the following criteria for a 30% fat cream:

1. Stage at 70 °C and a pressure of 60–70 bar
2. Stage at 70 °C and a pressure of 15–20 bar

For pasteurized cream having the same shelf life as fresh milk, homogenization is not necessary.

Heating and cooling. Whipping cream must be heat treated with an approved process. For fresh whipping cream, pasteurization is done mainly with a high-heat process, where temperatures > 95 °C are chosen. Whipping cream with an extended shelf life is manufactured by the UHT process and filled aseptically. Sterilized whipping cream is sterilized after the filling operation.

After heating, a shock cooling should be applied for fresh cream, using temperatures of < 10 °C (optimum 2–4 °C) in order to achieve good fat crystallization and foam stability.

Filling and packing. Filling is done into glass bottles or into one-way containers (for shelf-stable whipping cream) such as cups or bricks with user-friendly volumes of 150 g,

¹ Hydration: attachment of water molecules to a particle surrounded by water.

200 g, 250 g, 500 g. For large-scale users containers with a net volume of 2 l up to 15 l or churns of 20 l content are used.

Two methods are used in the application of aerosols:

- a) Aseptic filling of homogenized, UHT or sterilized cream into spray cans (used as one-way containers)
- b) Nonaseptic filling into so-called siphon bottles, in which after filling of cream and closing of the bottle, a cartridge with a compressed air is used

5.3.3. Coffee cream and sour cream

5.3.3.1. Coffee creamer

- Coffee cream is a shelf stable product, with a fat content of > 10 %. It is homogenized and UHT processed, filled aseptically or sterilized in the container.

Coffee cream is a long-shelf-life product, similar to UHT milk. Its key function is to whiten coffee, but it is also used in the preparation of food and drinks and for direct consumption.

Evaporated milk (see Section 9.3) is also a long-shelf-life product and has nearly identical characteristics. Coffee cream is slightly higher in fat content; evaporated milk has a higher dry matter level (due to evaporation of water). The important quality criteria are taste, whitening power and stability in hot coffee.

Production. First, the fat content must be standardized as described in Section 4.2.5.1. Coffee cream, treated by the UHT process, is filled aseptically into one-way containers of standard net volumes [10 ml (portion pack) up to 0.25 l].

When preserving coffee cream by the sterilization process, it is first fat standardized, then pasteurized at 90 °C, homogenized, filled into bottles, closed by crown corks and finally sterilized in retorts (see Section 9.3.1.5).

Homogenization. Coffee cream must be homogenized. This prevents a fat layer or fat plug in the container, thus improving taste, whitening power and stability.

Homogenization has a direct influence on the flocculation stability of coffee cream in hot coffee. A double-stage homogenization is optimal for UHT cream. The first homogenization is done before the UHT treatment; the second aseptic one is done after the UHT treatment. For both processes the pressure in the first stage should be about 200 bar and in the second stage about 50 bar. When sterilizing cream in the pack, homogenization has to take place before the sterilization, which again is a double-stage process using the same pressures (200/50 bar).

Flocculation of cream in hot coffee is due mainly to casein precipitation. For example, homogenized casein-free cream, enriched with whey proteins has significantly improved flocculation stability when it is preheated at 90 °C for 5 min because of whey protein denaturation (Geyer and Kessler).

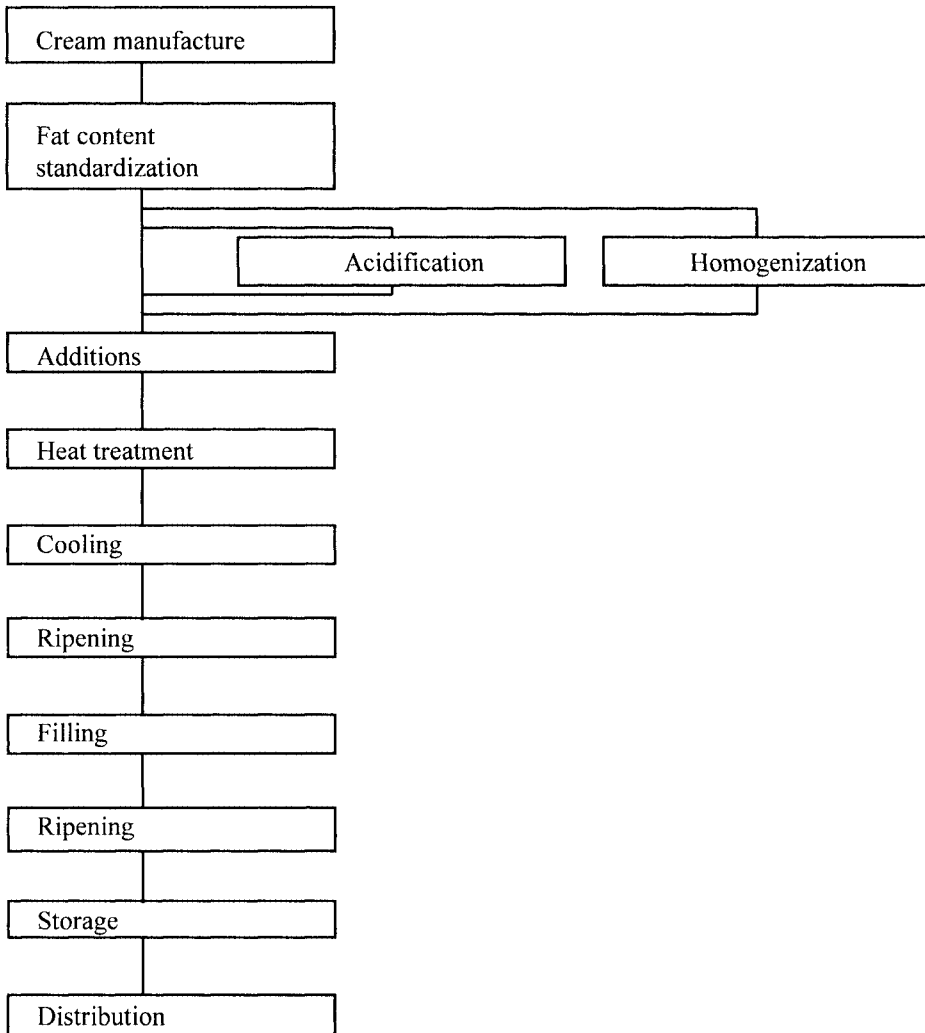
5.3.3.2. Sour cream

Sour cream is mainly used in prepared foods, less often in drinks or beverages.

Manufacturing. 2–4% of a special mesophile culture or butter culture is added to a fat-

standardized cream, heat-treated and chilled to 15–20 °C cream, and the final fat content is set. Once the cream has reached an SH value of 25–35, the cream is further chilled to 2–4 °C and is then filled into one-way containers or bottles.

Overview 5./3 Flowsheet for the manufacture of whipped cream



5.3.4. Quality evaluation

Organoleptic requirements are shown in Overview 5./4. For sweet (nonacidified) cream and whipping cream the criteria are appearance, flavor, taste, coliform bacteria and fat content. For whipping cream additional criteria are (after whipping) volume increase, settling and firmness of the foam.

For acidified cream, which can have a solid or creamy-liquid consistency, the criteria are appearance, taste, flavor, consistency, coliform bacteria, yeast and mold and fat content. Coffee cream (sterilized or UHT processed) is evaluated on the basis of fat separation, flocculation, color, taste, flavor, whitening power; further it is checked on fat con-

tent, nonfat dry matter, sterility and total dry matter content. The same requirements as for fresh milk are used for labeling, storage and distribution of milk beverages and cream products.

Overview 5./4 Organoleptic criteria for cream

Criterion	Coffee cream		Sour cream	Whipping cream (non-whipped)
	sterilized	UHT process		
Appearance	Yellowish after storage of >4 weeks; a slight creaming is possible, clean, slight cooked flavor possible, slightly bitter	White to yellowish creaming is possible after a storage of > 14 days, slightly viscous	White to yellowish, slightly creamy	White to yellowish
Flavor	Clean, rich body, slightly sweet to bitter, slight cooking taste possible	Clean, slight cooking taste possible	Clean, slightly acidic, rich	Clean
Taste		Clean, rich body, slightly sweet, slight cooking taste possible	Clean, milk-sour, flavorful	Clean, creamy, sweetish

5.4. Desserts and cream products

5.4.1. Terms and meanings

- Desserts are mixtures of cocoa, chocolate and/or fruit preparations with a high percentage of dairy ingredients with the addition of binding agents and sugar (saccharose).
- Cream products are similar to desserts but have a creamy consistency due to the incorporation of air or gas.

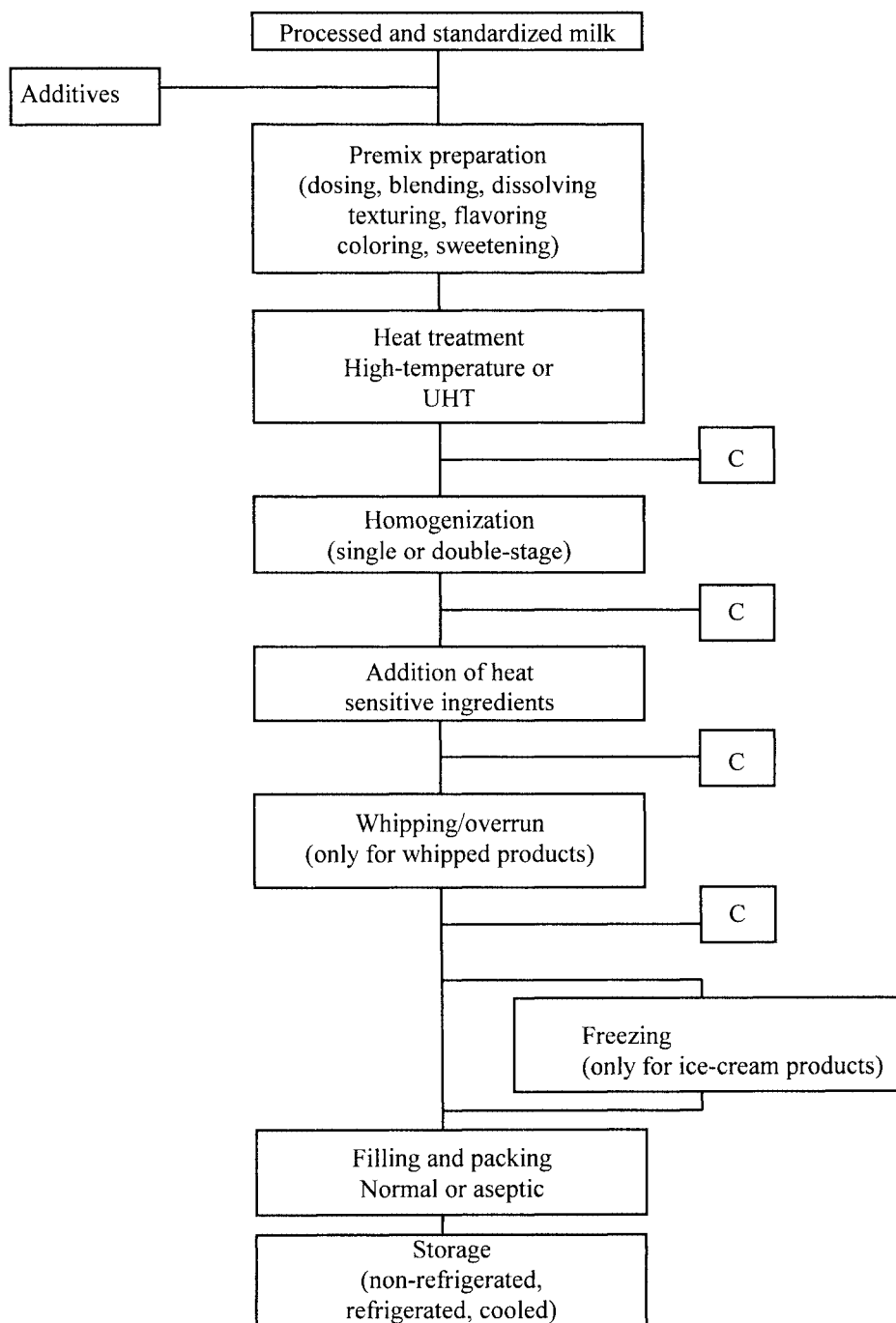
Desserts are tasty, easily digested food in consumer packs, which can be consumed not only as the final course of the main meal. They also serve as a fast-food item, low-calorie food or as a substitute for the main meal and can contribute significantly to a healthy nutrition.

Dairy-based desserts include acidified and nonacidified products such as cremes, puddings, creme fraiche, ice cream, jellies and milk cocktails. A chocolate dessert contains about 50% skim milk, 25% sugar and 25% cocoa or chocolate powder.

Cremes are basically food foams which obtain their specific consistency from their gas content. Here we include whipped cream with a volume increase (overrun) of 100–150%, yogurt/cream products with 30–70% and quarg cream with an overrun of 25%. A clear differentiation from “normal” milk products is sometimes difficult. For example, a stirred vanilla yogurt cannot be distinguished from a vanilla dessert creme. Another group is dessert powder, manufactured industrially and then prepared at home in form of milk desserts.

Other additives—apart from those imparting taste—are emulsifiers (mainly lecithin), sugar, artificial sweeteners (for calorie reduction), flavors, colorants, fibers (cellulose, polydextrose and others), egg powder, food acids (e.g., citric acid) and others.

Product specific consistency of desserts and cremes is decisively influenced by the addition of hydrocolloids as binding agents, in this case mainly gelatin. The level here is about 0.4–0.5 %.

Overview 5./5 Flowsheet for the manufacture of dessert products


C: Chilling subject to requirements

5.4.2. Process technology

Processes are designed for each specific product, and the available installations in the dairies are used, sometimes in modified form. A flowsheet is shown in Overview 5./5.

Of special importance are the formula and the preparation of the premix, as they determine the product quality to a high degree. Sometimes the additives must be dissolved separately in water. The heat sensitivity of the additives must be considered, and some components can be added only after the heat treatment. For preservation purposes fresh products are pasteurized using the high-heat process; long-shelf life products are UHT processed. For some products such as puddings, a hot filling at 65–70 °C is necessary and the product solidifies in the pack.

5.5. Reconstituted and recombined milk

- Reconstituted milk is a product which has been obtained by dissolving, dispersing, hydrating or emulsifying of dried concentrated dairy products (mainly milk powder) in the original quantity of water.

Reconstitution of milk from milk powder on an industrial scale is of interest mainly in tropical and subtropical climates or for supply in emergency areas. The reconstituted milk is pasteurized or UHT processed and is filled and packed like fresh milk.

- Recombined milk is made by adding individually processed, concentrated and dried dairy products to water and/or market milk products (milk or cream) and then jointly processing them.

Recombination offers the following possibilities:

- a) Manufacture of products with a significantly modified composition, which can meet nutritional requirements for dietetic purposes (modification of the casein/whey protein content, utilization of hydrolyzed lactose and others)
- b) Utilization of other food ingredients, creation of new blends, which still have the characteristics and properties of dairy products
- c) Consideration of nutritional requirements in other geographic regions
- d) Improvement of shelf life and storage stability

Reconstitution and recombination are used in the manufacture of market milk, cream products, evaporated milk, yogurt products, quarg and some types of cheese. Further, reconstituted milk is used in the preparation of starter cultures in dairies in order to provide standardized conditions for microorganisms.

Production. The production of reconstituted and recombined milk and dairy products is characterized by blending, dispersion, hydration, emulsifying and dissolving operations. The processes are basically identical to the ones used in dairies.

The manufacture of these products requires a higher amount of energy on a total basis, as the energy-intensive drying precedes the recombination process, and recombination requires additional energy.

5.6. Milk imitations

5.6.1. Definitions and products

Improved process design and more liberal legislation permit an ever-growing increase of new food ingredients. This results in some product groups which can be labeled milk imitation products. Sometimes we also find terms such as “milk replacer,” “milk imitation” or “products which can be confused with milk or dairy products.”

The International Dairy Union has made a distinction between substitution and imitation products and recommends the following definition:

- Substitution products are foods, which are destined to replace milk and dairy products (see “Code of Principles Concerning Milk and Milk Products”).
- Imitation products are substitutes for milk and dairy-based products which are similar in their general composition, appearance, characteristics and application to milk and dairy-based products, and replace (partially or totally) the milk components.

An exact differentiation is difficult with this definition. In most cases, these products are categorized as imitation products. It is more important, that the consumer can easily recognize the difference between these products and real dairy products.

Labeling. The five labeling elements (product type, list of ingredients, minimum shelf life, quantity and manufacturer) should not lead to the perception (according to the EU product labeling laws), that imitation dairy products are real dairy products. For example, some products such as soymilk, soy quarg, soy yogurt, butterine and imitation cheese are not permitted in the EU region.

Products. In many cases we find partial or complete replacement of the milk fat by vegetable fat. This occurs in butter imitations or other products such as coffee whiteners (i.e., milk contains vegetable fat) or cheese imitation products.

In some products, casein is replaced by vegetable proteins, mostly soy protein. Lactose can be replaced completely and sweetening agents can be incorporated, which makes these products more acceptable to consumers with a lactose allergy.

The advantages of these imitation products are mostly a significantly reduced cost, a wide variety of combinations and the reduction of the energy content. In many cases these products are offered as “light” products or have additional denominations such as “does not contain lactose,” “free from cholesterol,” “contains ... % of saturated fatty acids.”

The disadvantage is that most of the hydrogenated vegetable fats have a lower digestibility than milk fat, a lower biological value for vegetable proteins compared to milk proteins, and a lower bioavailability of calcium. A selection of milk imitation products is shown in Overview 5./6.

Additives are indispensable when it comes to achieving and stabilizing product characteristics (consistency, texture, microbiological quality), but they limit consumer acceptance in some cases. Additives are used for preservation and food acid control and as stabilizers, emulsifiers, colorants, natural, nature identical and artificial flavors. Problems may arise in the analysis of these compounds. Proper methods for the qualitative and quantitative determination of these additives still must be developed or must be standardized.

5.6.2. Soy drinks

Soy products can be found predominantly in the liquid product category; therefore, soy drinks are selected as an example of imitation products.

- A soy drink is an industrially manufactured liquid product, which is extracted from soybeans and is similar to cow's milk in composition, appearance and taste.

In many—mainly developing—countries, vegetable proteins, carbohydrates and fats are the basic source of human nutrition. Apart from cereals, legumes are in the forefront. Soybeans are the most important legumes in Asia and America and in Asia are one of the most important sources of protein and fat. Soybeans are different from other legumes in their high fat content and low starch content. Further, soyproteins have on average a higher content of essential amino acids than many other animal or vegetable proteins. The average chemical composition of some legumes is shown in Table 5./1.

Table 5./1 Average chemical composition of some legumes in %

	Protein	Starch	Sugar	Fiber	Fat	Ash	Others
Soybeans	39.0	4.0	5.9	5.0	20.0	6.0	20.1
Beans	24.3	47.6	5.9	4.9	1.8	4.2	11.3
Peas	27.8	48.7	4.8	5.7	1.4	3.2	8.4
Lentils	30.4	48.4	2.9	3.9	1.3	3.1	10.0

The lack of animal nutrients in many countries and especially the significantly more economical production of plant nutrients have resulted in the development of many dairy-like products in many countries. They are manufactured either as an alternative to cow's milk or in combination with cow's milk components.

Production. A basic flowsheet for the manufacture of a soy drink is given in Overview 5./7. Milling and preparation of soybeans are done to such an extent, that a concentrate is obtained which is fairly neutral in taste. According to the intended application, the process can be oriented toward continuation or to fractionation into individual components for a soy drink or a soy product (Table 5.2).

The desired product composition is prepared by blending water and the other ingredients in a blending vessel. Processing then follows the same operational steps as for fresh milk; i.e., after homogenization we have pasteurization for nonaseptic products according to an approved process and filling similar to fresh milk. For aseptic products, a UHT process and aseptic filling are the processing steps.

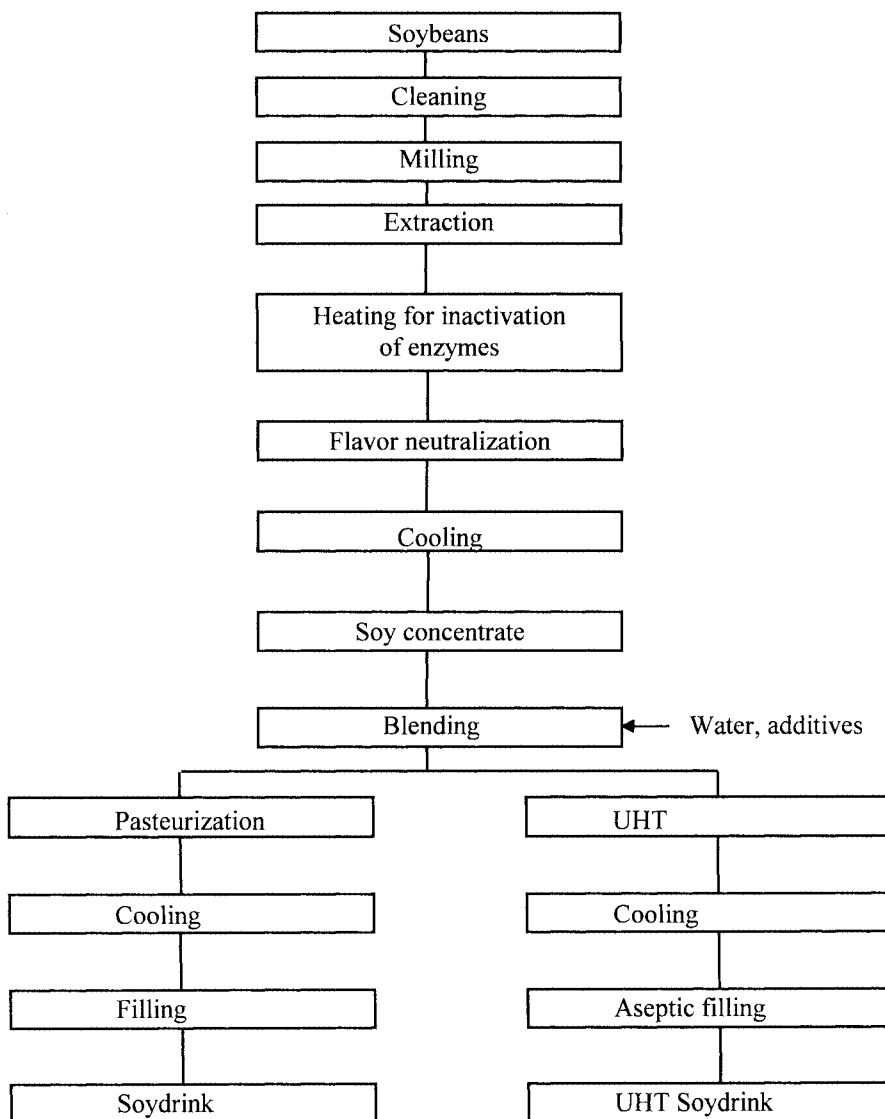
Table 5./2 Composition of two typical soy products

Ingredients in %	Soy drink 1	Soy drink 2
Water	90.4	87.5
Soy protein	3.6	1.5-2.0
Soy oil or other vegetable fats	3.0	1.0-1.5
Sugar	3.0	10.0

Overview 5./6 Selected imitation products from EU markets

Denomination	Key ingredients	Application	Replacement for
Beverages			
Mixed beverages	Skim milk, sunflower oil	In tea and coffee, for breakfast cereals, desserts and sauces	Whole milk (3.5% fat), partially skimmed milk (1.5–1.8 % fat) Fruit yogurt products
Mixed desserts with fruits	Skim milk, hydrogenated palm and soy oil, whey powder		
Blend emulsions	Skim milk, butterfat, vegetable fat	For whipping, decoration and for cooking	Cream, whipped cream
Foam sprays	Skim milk, hydrogenated vegetable fat, nitrous oxide	For desserts, in soups, for the surfaces of foods	Whipped cream, whipped cream in aerosol cans
Liquid coffee whitener	Skim milk, vegetable oil	In tea or coffee	Evaporated milk, whole milk, partially skimmed milk, milk powder
Powdered blends	Skim milk, vegetable fat	For cooking, baking, in coffee or tea	Cheese (layered cheese)
Colloid blends	Water, caseinate, vegetable oil, cheese, whey	For cooking and topping	Cheese (layered cheese)
Bread spreads	Skim milk, sunflower and soy oil	For cooking and direct consumption	Butter
Blended fat products			
Fat blend 80 % fat	Cream, vegetable oil, hydrogenated vegetable fat	As fat for spreading, cooking, roasting and baking	Butter
Breadspread made of vegetable oil and butter, 65% fat	Sunflower oil, water, butter, hydrogenated soy oil, soy oil, skim milk, palm oil	As fat for spreading, for cooking and baking	Butter
Fat product 60% fat	Skim milk, soy oil, hydrogenated soy oil	As fat for spreading, for cooking and baking	
Fat product 41% fat	Buttermilk, butterfat, soy oil	As fat for spreading	Butter, milk fat product
Fat product 25% fat	Skim milk, buttermilk, vegetable oil, hydrogenated vegetable oil	As fat for spreading	Butter, milk fat product, cream spread
Products existing for a longer time in the market			
Powdered coffee whitener	Vegetable fat, dairy protein	For coffee and tea	Cream, whipped cream
Powdered emulsion	Vegetable fat, dairy protein	For whipping, decoration and cooking	Milk powder, evaporated milk
Soy drink	Water, soybeans	As Beverage	Whole milk, partially skimmed milk
Soy dessert	Water, fruits, soy	As dessert	Yogurt, fruit yogurt
Tofu	Soy	For foods of all kind	Quarg

Overview 5./7 Flowsheet for the manufacture of a soydrink





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6 Butter Manufacture

- 6.1. Terms, importance and characterization of butter**
 - 6.2. Technology of butter manufacture**
 - 6.3. Process lines for continuous butter manufacture**
 - 6.4. Batch butter manufacturing**
 - 6.5. Fat concentrate chilling process (separation process)**
 - 6.6. Indirect biological acidification process (IBA)**
 - 6.7. Fat emulsion process**
 - 6.8. AMF manufacturing process**
 - 6.9. Mixed-fats products manufacturing process**
 - 6.10. Manufacturing process for cholesterol reduction**
 - 6.11. Packaging and labeling of butter**
 - 6.12. Storage and transport of butter**
 - 6.13. Quality evaluation**
 - 6.14. Butter yield**
-



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6 Butter Manufacture

6.1. Terms, importance and characterization of butter

6.1.1. Terms

- Butter is a fat-in-water emulsion having a solid, plastified consistency. It is manufactured from milk, mainly from nonacidified (sweet) or acidified cream. For acidification, food-grade lactic acid and flavoring bacteria and/or lactic acid concentrate are used. When heating to 45 °C, a clear milk fat layer as well as another layer is formed, containing water and the fat-free dry matter.
- Butter consists of 80–90% milk fat with a maximum of 16% water and other dairy ingredients. Permitted additives are water, salt, and eventually beta-carotene as a coloring substance. The fat-free dry matter content should not exceed 2%.

Butter—and other fat spreads—can be characterized as a type of emulsion. In milk and cream, the serum is the continuous phase, in which fat is distributed as a dispersed phase. In butter we have a reversal of the phases; fat has become the continuous phase. A clear distinction can be made between cream and butter in terms of the phase distribution.

Types of butter. The types of butter are mainly characterized by a more or less pronounced acidic character:

- a) Sour cream butter, made from bacterially acidified butter with a pH ≤ 5.1 in the serum
- b) Sweet cream butter, from nonacidified butter, to which even after buttering no bacterial cultures have been added, with a pH of ≥ 6.4 in the serum
- c) Mildly acidified butter, made from partially acidified or sweet cream with a pH of 5.2–6.3

Additional quality criteria (see Section 6.13) characterizes the types.

Butter can also be manufactured by recombination processes (see 5.5), using milk, cream, butter, anhydrous milk fat (see 6.8), butter oil or concentrated butter (fat content $> 90\%$), having a fat content of 80–90%, maximum water content of 16% and a maximum level of 2% of nonfat dry matter. Whey butter is a product made from whey cream or a blend of whey cream and milk and/or cream and has the same composition as recombined butter.

Other commercial terms are fat-reduced butter, low-fat butter and milk fat spread, and the fat content can be seen in Table 6.1. These products are made from milk, cream, butter, anhydrous milk fat, butter oil or butter concentrate.

Other butter preparations include butter with herbs and anchovy butter, which contains additives that give them their characteristic flavor; still, they are basically butter. Butter is a spreadable fat, for which we can apply the following definition:

- Fat spreads are solid, plastified foods of the water-in-fat type of emulsion, which by principle contain an aqueous phase as well as fats and oils. These fats and oils are foods on the basis of fatty acids, have a vegetable, animal or marine origin, or are made from milk.

Apart from the basic components, these fat spreads can contain vitamins, salt, colorants, suitable proteins (including gelatin), dairy components, differently prepared natural starches, mono-, di- and oligo-saccharides and maltodextrin. Further, butter cultures can be added, as used for butter.

A possible classification of butter is shown in Overview 6./1, where the types can have different denominations depending on the different states.

Overview 6./1 Fat spreads

Fat content in %	Milk fat products Milk fat content 100% of total fat	Fat blends product (Milk fat content \geq 15% and \leq 80% of total fat content)	Margarine product (milk fat content \leq 3% of total fat content)
80–95	Butter	Fat blends product	Margarine
>62–<80	Milk fat spread	Milk fat spread	Fat spread
60–62	Fat-reduced butter	Fat-reduced fat blends	Fat-reduced margarine
>41–<60	Fat-reduced milk fat spread	Fat-reduced fat blends spread	Fat-reduced fat spread
39–41	Low-fat butter	Low-fat fat blend	Low-fat margarine or Minarine
<39	Low-fat milk fat spread	Low-fat fat blend spread	Low-fat fat spread

6.1.2. Importance and composition of butter

Butter is a food fat which typically has a good taste and flavor. These characteristics are due mainly to the natural composition of the milk fat—resulting from feeding—as well as physical and biochemical ripening processes as well as additives during its manufacture. Good digestibility and utilization by the body (>90%) are due to its melting point (near body temperature). Further, butter contains important fat-soluble vitamins, especially vitamin A.

The cholesterol content (see Section 2.3.1.2) is in the range of 240 mg/100 g. Cholesterol has become a marketing concern as it is considered a health risk, however according to lipid theory, there still is no clear proof of a relationship between food cholesterol and serum cholesterol (formed in the body at up to 1000 mg/day). With suitable processes, the cholesterol content in butter can be reduced by 60–90% of the initial content (see Section 6.4.5), and consumers attracted by the lipid theory can be reconverted.

The functionality of butter is evidenced by its firmness and above all by its spreadability at room temperature (about 20 °C) and at refrigerated temperatures (4 °C). These texture characteristics are influenced above all by the consistency of butter (see 2.3.2.1). The consistency of butter is controlled by the fat content, fat composition, process technology and the structure; consistency and structure are closely interrelated.

- The structure is characterized by the quantity, distribution and agglomeration of the individual components, such as the quantity and distribution of buttermilk or water droplets, quantity and state of free fat, quantity and size of the fat globules in butter, possible fat separation and a possible brittleness of the butter.

Like all foods, butter has a specific structure, by which we mean how the individual components are structured (e.g., size, shape and structure of the fat crystals, structure of the semi-solidified and liquid fat of the butter, and structure of the serum droplets).

6.2. Technology of butter manufacture

This technology is characterized by the process complexes, the cream treatment and the churning process proper. The unit operations include preparation of the butter culture, packing and storage of butter as well as the quality evaluation.

An important technological process is butter formation, during which the reversal of the type of emulsion takes place. This phase reversal characterizes the so-called buttering processes with their specific process lines. The butter processes can be classified as follows:

- a) Fat globule agglomeration process, which can be a periodic (noncontinuous or batch type) or continuous
- b) Fat concentrate chilling process (separation process)
- c) Recombination process

Further, we want to discuss the process for the manufacture of butter oil (pure milk fat) and a process for the fat fractionation. Overview 6./2 shows a basic flowsheet for the manufacture of butter as applied for the fat globule agglomeration process. This process is, at least in Europe, widely applied, as the butter quality obtained meets consumer expectations.

6.2.1. Cream treatment

Of great importance for the butter manufacturing process is cream, the raw material, and its treatment, as

- a) The optimal process of buttering depends on it.
 - b) It characterizes the butter quality.
 - c) It can influence the butter fat content in a significant way.
- Cream is obtained by separating milk (see 4.2.3 and 5.3), and serves as the basic raw material in butter manufacture. It is a high-temperature heat-treated (minimum 85 °C) nonhomogenized product.

For the entire cream treatment, mechanical influences should be kept to a minimum (see 2.3.1.2). A practical compromise has to be found between the required flow characteristics, good blending and low mechanical stress when transferring and storing cream.

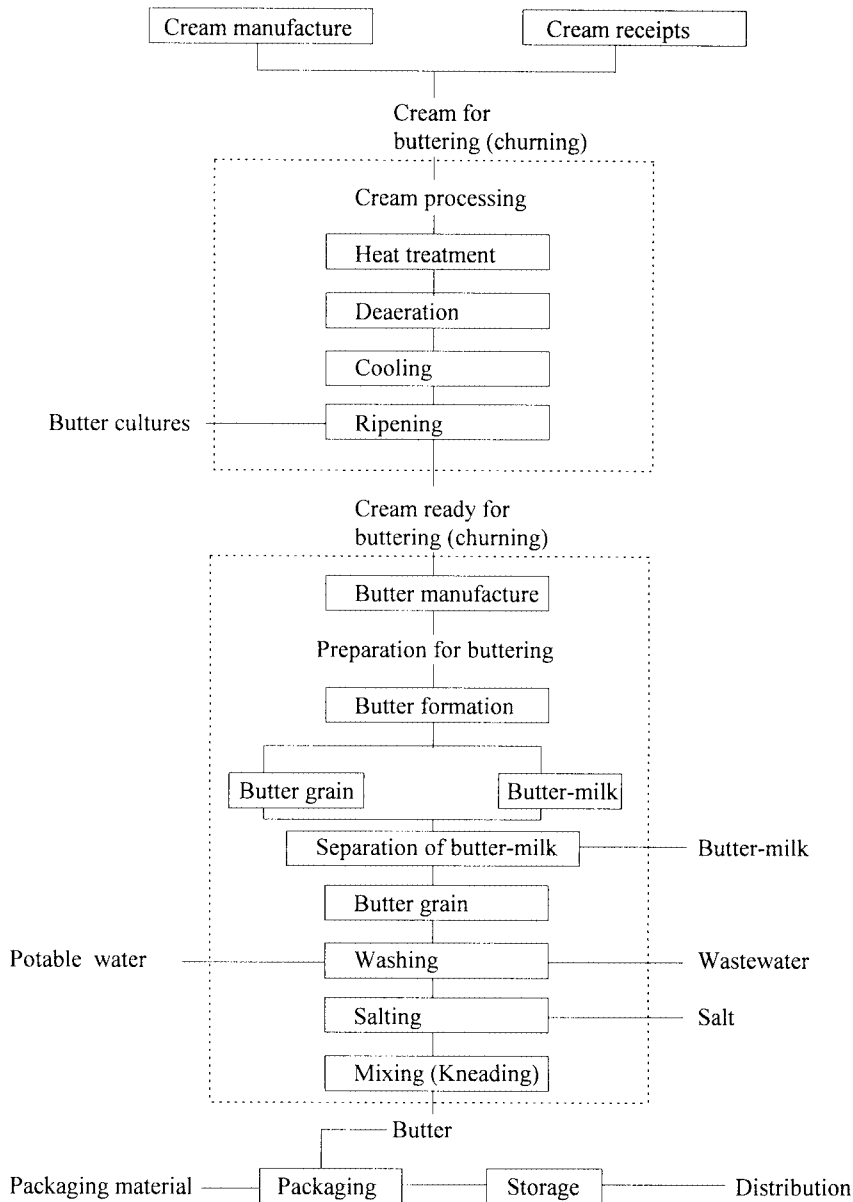
- Transfer and mixing processes have to be as gentle as possible during cream treatment.

Importance of the fat content

An important product aspect is the fat content of the cream, as the cream treatment and linked fat standardization are the initial operation of the fat concentration process, which characterizes butter. The fat content which is selected depends on the buttering process; for a classical process a fat content of 38–40% is selected. Cream with a fat content of 40% has the following composition:

Fat	40.0%	Protein	2.1%
Water	54.5%	Lactose	3.0%
		Minerals	0.4 %

Overview 6./2 Basic flowsheet for butter manufacture (fat globule agglomeration process)



In cream the following modifications take place with increasing fat content:

- Reduction of the serum level—the acidification capabilities are reduced as the fermentable fraction is reduced
- Increase of viscosity—greater losses in adhesion, reduced flow characteristics, reduced blending and transfer capabilities,
- Reduced density—cream with a fat content of 40% has a density of 0.993 kg/l at 20 °C, therefore for practical reasons we normally use $\rho = 1 \text{ kg/l}$, or the density is cal-

culated as a function of the fat content (see below):

$$\rho = \frac{1030 \text{ kg} / l - f_C}{1000\%}$$

- d) Reduction of the average distance between the fat globules (Table 6./1), a favorable precondition for fat globule agglomeration during butter formation.

Table 6./1 Average distance of the fat globules from each other as a function of the cream fat content

Product	Fat content in %	average distance of the fat globules in μm
Milk	3	7
Cream	20	2.2
Cream	30	1.4
Cream	50	0.56
Cream	74	0

In addition to the aspect mentioned under d) it should be noted that with fat levels of >75% fat does not exist in the form of individual globules but in agglomerates (clusters). Therefore, during storage, the globule membranes can sometimes break up, and a continuous fat phase develops (creation of a double emulsion).

- Due to high viscosity and the resulting deteriorated blending of cream, the fat content of cream during its manufacture has to be kept as constant as possible.

6.2.1.1. Cream deliveries

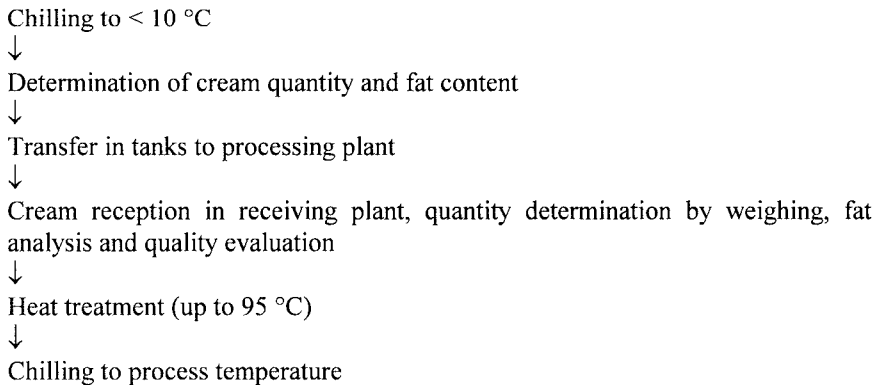
Apart from the cream directly manufactured in the dairy, other cream can be used, such as cream transferred from external plants. This requires transportation of cream over long distances.

- Externally supplied cream is a cream, that is fat-standardized, cleaned, heat treated (>85 °C) and chilled, and transported from one dairy to another processing plant.

The SH value of externally supplied cream should be a maximum of 6 and the temperature should be ≤ 6 °C. Proof of high-temperature treatment should be available, and there should be no inhibitors. Coliforms should be absent in 0.1 ml, and the TPC should be < 100,000. The organoleptic characteristics should be equivalent to those of normal cream. Retention samples should be kept at both the supplier's and receiver's end for quality assurance reasons.

In some cases, the butterfat can be transported to the manufacturing plant in form of a high-fat milk (fat content 8–10%). This process makes sense only in cases in which the receiving plant also requires large milk quantities, which are generated during separation. For cream deliveries the following process is chosen under normal conditions:

Cream manufacture and fat standardization (35–45%)
 ↓
 Heat treatment (up to 95 °C)
 ↓



Cream deliveries have a few inherent problems which have to be considered. The high viscosity of the cream can cause high transport losses due to adhesion in the tanks. Therefore cream pipelines and tanks should be washed out with small quantities of skim milk. Water should be used only sparingly for rinsing, in order not to later exceed the foreign water content in buttermilk.

- Cream has to be treated very gently during transport. The tanks have to be filled completely. For transfer of cream at temperatures $< 30\text{ }^{\circ}\text{C}$, displacement pumps should be used.

6.2.1.2. Cream heat treatment, chilling and deaeration

Cream heat treatment. The purpose of the cream treatment is:

- a) Destruction of spoilage pathogen microorganisms, which negatively influence cream ripening and butter quality
 - b) Inactivation of fat and protein splitting enzymes (especially lipases), which can cause a fat splitting and quality reduction in butter
 - c) Slight reduction of the cream viscosity and therefore better processing possibilities.
- Cream for butter must be heated to at least $85\text{ }^{\circ}\text{C}$.

In most cases treatment temperatures in the range $90\text{--}110\text{ }^{\circ}\text{C}$ are selected. With temperatures $> 115\text{ }^{\circ}\text{C}$, a deterioration of the membranes of fat globules can be expected, sometimes causing a nondesirable release of free fat. The cooking taste which is sometimes noticed, disappears in butter after a few days.

These temperatures—relatively high compared to those of milk heat treatment—are necessary as microorganisms are more resistant to heat treatment when they are surrounded and protected by a fat layer.

Cream cooling. Immediately after the heat treatment, a cooling takes place, with temperatures reaching the solidification temperature range ($T < 22\text{ }^{\circ}\text{C}$). The final temperatures are subject to the temperature profile of the cream ripening process (see 6.2.1.3.3)

Cream deaeration. Fat is the main carrier for all taste and flavor compounds in milk, but it also brings an off-taste and off-odor into the cream, which is then later transferred into the butter. These negative quality effects are due mainly to bad feed and a bad ambient air (barn air), which influence the milk.

- Deaeration removes the nondesirable taste and flavor compounds to a large extent.

Further, oxygen is removed from the cream, preventing the development of harmful aerobic bacteria and fat oxidation. As both desirable and nondesirable taste components are removed during the deaeration step, special importance must be given to good flavor development during the cream ripening. If the raw milk is of good quality, the cream deaeration can be bypassed.

Process. Deaeration is done in conjunction with heating and cooling in vacuum vessels (Figure 6./1). For this, cream is pumped after heating into the vacuum vessel (4). Due to the lower pressure (0.8–0.85 bar), a boiling point reduction occurs with an instant steam flash. At this time, the compounds which are to be removed are absorbed by the steam and are entrained. A vacuum pump keeps the pressure constant and the steam is evacuated.

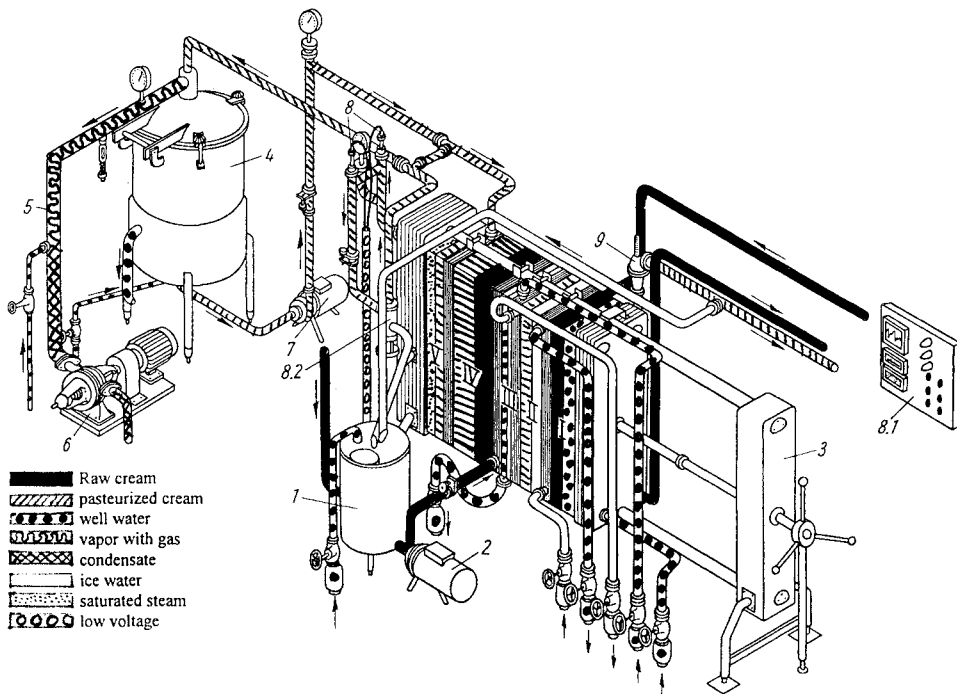


Figure 6./1 Process line for cream treatment; flow rate 5000 l/h

(1) Buffer tank with floating device (2) Centrifugal pump (3) Plate heat exchanger (I Raw cream cooling, II Ice water cooling, III Fresh water cooling, IV Heat exchanger for heat recovery, V Heater) (4) Deaeration chamber (5) Injection condenser (6) Water ring vacuum pump (7) Centrifugal pump (8) Thermometer (8.1) Control panel for regulating and switching devices (8.2) Switching valve (9) Thermometer

Cream heating. Here mostly plate heat exchangers are used, which are designed to accommodate the higher viscosity of the cream, and therefore lower turbulence between the plates.

For smaller capacities ($V < 500$ l/h) the cream heating installation is integrated into the frame of a milk plate heat exchanger. For larger capacities complete cream process lines (Figure 6./1) are installed, which have an automatic temperature control with integrated heat recovery as well as the unit operations of deaeration and cooling. In a separate frame, a raw cream cooling installation can be found.

6.2.1.3. Cream ripening

This unit operation serves as an intensive preparation of the cream for the churning process. Here we distinguish between a physical ripening and a biochemical ripening. The following criteria are influenced by the cream ripening:

- a) Consistency, firmness and spreadability of the butter
- b) Basic water content of the butter during the manufacturing process (bound water in butter, which cannot be removed by any mechanical treatment)
- c) Buttermilk fat content, which has to be minimized
- d) Acid content and flavor of the butter during the biochemical ripening

Physical ripening is required irrespective of the type of butter manufactured. For the manufacture of sourcream butter, the biochemical ripening—which causes the acidification of the cream—is combined with the physical ripening. The time-temperature profile which is selected is then referred to as the ripening process.

Cream ripening vessels. Ripening occurs in special vessels, so-called cream ripeners (cream tanks, silos) which are used simultaneously for storage, fat crystallization, biochemical ripening and sometimes temperature control (Figure 6./2). The installed stirring system has to provide good mixing of the cream with a very gentle treatment, so that the fat globules are not degraded and “oiling-out” effects do not occur by releasing some free fat.

Further requirements are sensors (Figure 6./3) for temperature and pH control. Additional CIP connections are required. The cream ripening vessels are double walled to contain the heating and refrigeration medium. For larger capacities, cream is passed through plate heat exchangers for temperature control, using positive pumps.

Volumes of these cream ripeners depend on the capacity and the design of the processes and are in the range of 6000–100,000 l. The large-scale cream silos serve for a longer storage of cream.

6.2.1.3.1. Physical ripening

Physical ripening serves to restructure the liquid fat (after heating) into a more or less solid crystalline state, which is the basic requirement for a solid, plastified structure of the butter.

For the control of these physical processes, we have to know the type of fat, fat composition, melting and solidification patterns, as well as the changes in the membranes of the fat globules, and they will be discussed in detail hereafter.

Fat composition. Fat is a triglyceride (see 2.3.1.1) and its melting and solidification (crystallization) behavior depends on the attached fatty acids, which provide an indication of the hardness of butterfat.

This natural hardness is caused mainly by seasonal feeding of the milk animals. Winter feed with a great deal of dry feed or roughage yields a hard butterfat with a high percentage of saturated and short-chain fatty acids and few double bonds in the fat mole-

cules. Summer feeding (green grass) results in fat with longer chains and a higher percentage of unsaturated fatty acids with many double bonds. We therefore distinguish between summer fat and winter fat or summer cream and winter cream.

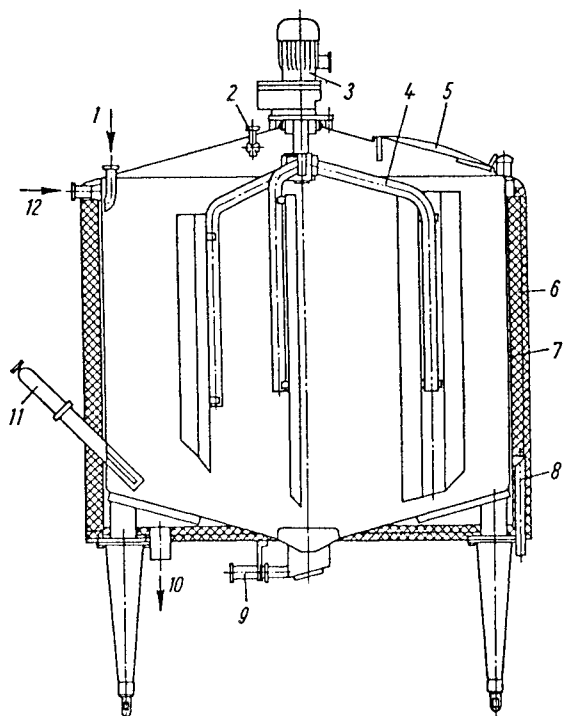


Figure 6.2 Cream ripener, cylindrical form, type ZRA

(1) Cream inlet (2) Device for chemical cleaning (3) Stirrer motor (4) Stirrer (5) Lid (6) Insulating layer (7) Chamber for tempering water (8) Water overflow (9) Cream discharge (10) Discharge tempering water (11) Sensor for pH and temperature control (12) Inlet for tempering water

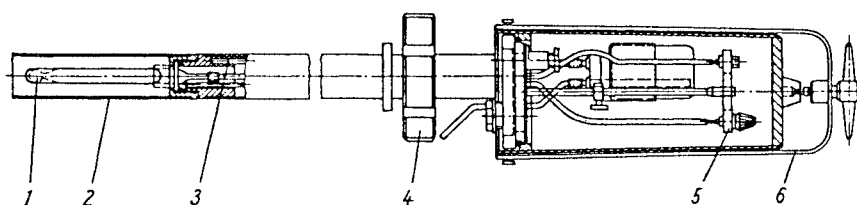


Figure 6.3 Sensor for pH and temperature

(1) pH electrode (2) Protective cover for electrode (3) Double resistance thermometer (4) Fitting for installation on cream ripening vessel (5) Clamp for electrical connection of electrode and thermometer (6) Protective cover

The percentage of saturated and unsaturated fatty acids can be determined from the iodine number or the refractive index, from which we can estimate the hardness and sometimes on the solidification performance of the fat.

- The iodine number indicates the amount of iodine (halogene), which is required to saturate the double bonding in 100 g of fat.

If the refractive index RI is determined with a butter refractometer, the iodine number can be calculated as follows:

$$I = 3.81 \times RI - 128.85$$

Melting and solidification performance. Optimal fat crystallization during the cream treatment has a decisive influence on the butter formation and on the quality of butter. The type and means of crystallization (crystallization kinetics) can be influenced by the temperature profile of the cream. Once the fat is in the range of the melting and solidification temperature, each further temperature reduction disturbs the solution equilibrium of the fat molecules, which results in an supersaturated state of the solution. As a result, initially small crystals are formed, which grow steadily into larger crystal structures. Fat crystallization is a slow process, which can last for hours, even for days.

Crystal formation in the fat globules has been elucidated to a large extent by electron microscopy. According to Precht et. al¹ four different fat globule types can occur at a constant temperature profile of 11–15 °C:

- Type 1 Fat globules with a thin peripheral crystal layer and a liquid interior
- Type 2 Fat globules with a thin peripheral crystal layer as well as crystalline fat agglomerates and a little liquid fat in the interior
- Type 3 Fat globules with a thick crystalline shell and a liquid core
- Type 4 Fat globules with a thick crystalline shell as well as crystalline agglomerates and a little liquid fat in the interior

The frequency of the occurrence of these types can be controlled by a variable temperature profile. This makes it possible to influence the consistency of butter relatively independently of the composition of the fat.

It becomes evident when observing the type of fat globules, that during the crystallization a fractionation of the fat takes place (in stages). Demixing of the fat globules takes place in such a way, that the liquid fraction migrates to the center of the globules. The higher melting fractions attach themselves below the membrane in the form of a more or less pronounced crystalline shell. Further, we also find solidified fractions as “fat grains,” mixed with liquid fat and semi-solidified fat in form of gel spheres.

Melting and solidification curves. In order to achieve optimal solidification by using a controlled temperature profile, the determination of the iodine number is insufficient, as it characterizes only the ratio of “hard” (or higher melting) to “soft” (lower melting) fats. It becomes necessary to record the melting and solidification curves, from which the peaks of the temperature set points during the tempering of the cream can be derived.

To record the so-called alpha curves, pure butter oil is separated from the melted butter and cooled in a water bath in a slow and controlled way. The continuously recorded temperatures are then presented in the form of curves on a chart.

The solidification curve (Figure 6./4) shows a constant temperature reduction to 22 °C. Thereafter the speed of the temperature reduction is noticeably reduced, and peaks are shown at 19.0 °C and 14.7 °C. The peak at 17.5 °C is the first solidification maximum (point); after another increase and decrease of the refrigeration velocity, a second solidification peak is reached at 14.7 °C.

The melting curve is recorded in the reverse sense. The temperature profile for the ripening process is derived from the peaks of these curves (see 6.2.1.3.3). The different

¹ Precht, D.; Peters, K.H.; Free, E.: Die Konsistenz der Butter, *Milchwissenschaft* 36 (10,11,12), 1981 und 38 (12), 1983.

patterns of the heating and cooling curves are due to the liberation of the crystallization energy and the absorption of melting energy. Table 6./2 shows how the crystallization temperatures can be selected as a function of the iodine number or the refractive index.

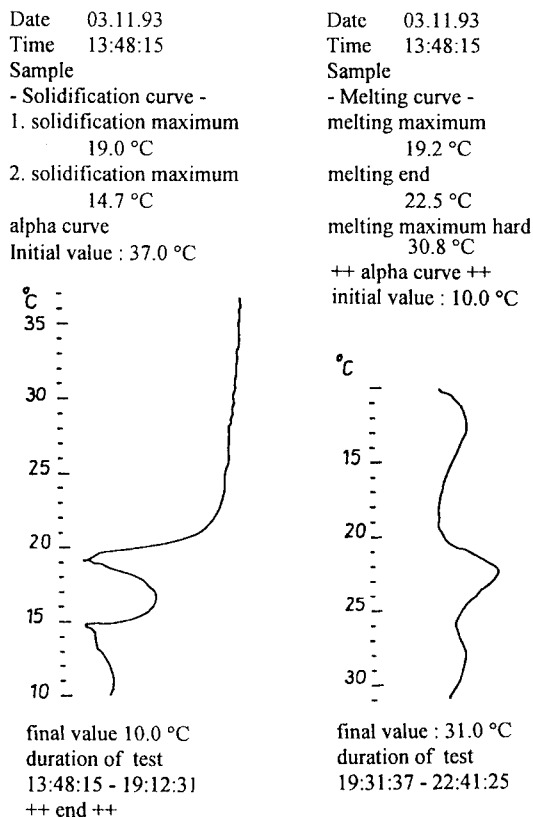


Figure 6./4 Melting and solidification curves of milk fat

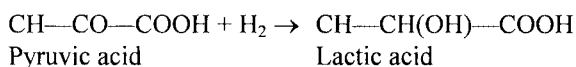
Influencing the fat globule membranes. During fat crystallization the volume of the fat globule is reduced. This causes a reduction of the boundary layer forces in the area of the membrane in the direction of the aqueous phase, and the membranes of the fat globules become unstable through the peripheral crystalline layer. Further, the crystals damage the membranes to such an extent, that liquid fat can migrate through the membrane during mechanical treatment.

Table 6./2 Optimal Crystallization temperatures of butterfat as a function of iodine number and refractive index

Iodine number	Refractive index	Optimal crystallization temperatures
< 28	< 41.2	
29-31	41.3-42.0	6-7 °C
32-34	42.1-42.8	
35-37	42.9-43.6	
38-40	43.7-44.3	> 10 °C
> 40	> 44.4	

6.2.1.3.2. Biochemical ripening

During the physical ripening, time-temperature processes are incorporated which generate biochemical reactions when lactic acid producing cultures are added (see 6.2.2). The objective is, to generate a typical acid level (pH value) and flavor which are characterize sour cream butter. When cultures are added (containing the lactic acid bacteria), lactose is fermented through various steps into pyruvic acid, which is then reduced to lactic acid.



Other fermentation products are found, such as small quantities of acetic acid, propionic acid and carbon dioxide. The generated acid causes some denaturation of the casein, which modifies the dispersed cream system in such a way, that the fat can be released more easily from the serum during butter formation.

Further formation of the butter flavor (diacetyl) occurs. At a pH of 5.0–5.2, lactic acid displaces citric acid from its salts, and the released free citric acid, in the presence of lactose, is converted into acetone and diacetyl by the flavor compounds. The same fermentation products can form flavor precursors directly from the citrates.

Diacetyl formation can be enhanced by

- a) Incorporation of air by intensive stirring of the cream during the first part of the ripening time
- b) Ripening temperatures < 15 °C in the second part of the ripening period
- c) Maintaining the optimal pH (<5.2)
- d) Addition of 0.15 % citric acid to the cream

The level of diacetyl in sourcream butter is 0.5–2.0 mg/kg butter.

Process

Foam-free transfer of cream into the cream ripener after shock cooling (at crystallization temperature)

↓

Addition of 2–8% of butter culture, when the tank is filled at one-quarter to one-third, blend well

↓

After filling of the cream ripener, continue stirring and store for 2–3 hours at the selected crystallization temperature

↓

Modification of the crystallization temperature and setting of the ripening temperature for the second phase of the ripening process (by heating the cream (to 24–27 °C) or cooling)

↓

During the first part of the acidification stir for 5 minutes every 2 hours, and constantly control the acidification process by checking the pH (titrable acidity too)

↓

After reaching the selected pH value or if the acidification has gone too far, cool to < 15 °C

↓

Evaluate ripening stage

↓

Adjust buttering temperature

The correct ripening stage for buttering has been reached by the cream, when there is sufficient fat crystallization and a proper pH value. According to the type of butter and the quality, the pH can be found in the range of 4.8–5.2. The proper ripening stage can also be found by determining the percentage of lactic acid developed (titrable acidity).

Butter temperature. Shortly before the buttering process, the cream temperature must be checked and must be adjusted if required.

- The optimal buttering temperature is 11–15 °C

It depends on the process, cream fat content (a high fat content requires a low temperature) and the seasonal ambient temperatures. For tempering of cream, either ice water or hot water is pumped through the jacketed tank, or the cream passes through a plate heat exchanger.

- When preheating, the warm water should not exceed a temperature of 27 °C.

6.2.1.3.3. Ripening process

The ripening process is basically a time-temperature process, to which the cream is subjected to. The profile is selected in order to obtain the desired type of fat globules and, if desired, to have simultaneous acidification and flavor development.

Each process has its own time-temperature profile. For an exact profile, the final temperatures of the different intervals for the peaks of the melting and solidification curves for each fat must be selected, and the process is set up. The temperature for the melting point of a curve cannot be exceeded.

- For all tempering processes, a temperature difference of $\Delta T \leq 4$ °C should be maintained between heating water and final cream temperature in order to avoid melting of the crystals.

All processes have different temperature profiles, and we distinguish between a cold/warm/cold ripening (also known as the Alnarp process), a warm/cold/cold ripening, a warm ripening and a cold ripening.

Cold/warm/cold ripening. This process is used during the winter months for a hard butter-fat, as here we see mainly the formation of fat globules of type 4 (see 6.2.1.3.1) with a thick crystalline shell. The result is that during the buttering process a high percentage of fat globules remains intact and the butter has low hardness (≈ 0.8 N); i.e., it remains soft.

Cream is rapidly cooled to 5 °C and is stored at this temperature for 2–3 hours. In this phase we can expect a temperature increase of 1.5–2 °C due to the release of crystallization energy. During this cold storage, mechanical stress (mixing, pumping) should be avoided in order not to disturb the crystallization processes and to avoid the release of liquid fat through the membranes of the fat globules.

For the next warm phase, the temperature selected must be about 1.5–2 °C below the melting maximum. Here the short-chain, low-melting triglycerides melt; the shell-forming triglycerides remain in a crystalline form. The entire process takes about 2–3 hours.

The warm phase of sour cream butter manufacture is also the acidification phase. Added starter cultures cause acidification and reduction of the pH. The warm phase must be extended until a pH of 5.6–5.2 is reached.

During the ensuing second cold phase, the crystalline fat fractions are stabilized, and we observe a postacidification with flavor development. Temperatures are in the range of 8–12 °C, and storage time is 12–15 hours.

A buttering temperature of 11–15 °C must be set up. The acidification process can be monitored by determining the pH; once the target pH has been reached, chilling can commence automatically. In case the pH cannot be measured, the beginning of the cooling phase after the main acidification phase can be determined by measuring the titrable acidity.

$$SH - number = \frac{100\% - fat_{cream}}{4\%}$$

Warm/cold/cold ripening. This process is mainly suited for a soft fat (with typical summer feeding) and leads to fat globules without shells of the type 2, which are easily destroyed during the buttering. This butter shows only a few intact fat globules and a relatively homogeneous distribution of the crystalline fat. Hardness of such butter is significantly higher (≈ 1.5 N) than that of butter from the Cold/warm/cold process.

After heating, cream is cooled to 21–23 °C, and after adding the starter culture, the acidification and at the same time the crystallization of high-melting point triglycerides are initiated. After 2–3 hours (at pH 5.7–5.9) it is chilled to 6 °C, and after another 2–3 hours it is reheated to 13–14 °C. At this temperature cream is stored for about 14–18 hours until the final buttering takes place; fat crystals continue to be formed. Then the buttering temperature must be adjusted.

Warm ripening. The acidification of the cream occurs at 18–21 °C at a pH of 5.1–5.5 during 4–6 hours. If the acidification occurs too rapidly, the cream is cooled to buttering temperature.

Cold ripening. Here the initial cream temperature is 13–16 °C, which is maintained for 16–22 hours until buttering occurs. The ripening level is not always at its optimum, as crystallization and acidification take place under suboptimal conditions.

Although the cold and warm ripening processes are less time and energy intensive, there is a higher risk for the butter quality. Further, a varying, sometimes significantly higher level of buttermilk fat must be expected, as buttering takes place under suboptimal conditions.

6.2.2. Butter cultures

In the classical production process for manufacturing sour cream butter, a blend of different types of harmless mesophilic lactic acid bacteria, mostly of the genus *Lactococcus* (see 2.4.3, Overview 2./8) is used for the acidification of cream. They produce mainly lactic acid by cracking lactose and also glucose, and flavors (acetone, diacetyl), carbon dioxide and other volatile gases.

Specialized laboratories prepare blends of different kinds of microorganisms, the main criterion being a more or less intensive flavor development. The butter plant prepares an operating culture from the mother culture.

Growth of these types of bacteria takes place in the temperature range 10–40 °C. Their acidification capability should be such, that milk at 21 °C should solidify within a period of 17 hours. The incubation temperature should be selected so that after 7 hours an SH value of 20 is reached; after 24 hours the SH value should be at 35–38 or the pH

should be at 5.5–5.3. [Refer to Table 2./7 for conversion of SH to % lactic acid (titrable acidity).]

Once these values have been reached, the logarithmic phase of the bacterial growth stops and a further subcultivation must be done. If the culture is not used once the acidity has been reached, the culture must be cooled and stored at 2–5 °C, in order to avoid superacidification.

Acidification stops at an SH value of 40–45; bacteria do not survive this acidity level. Figure 6./5 shows a desirable acidification pattern (according to Schulz).

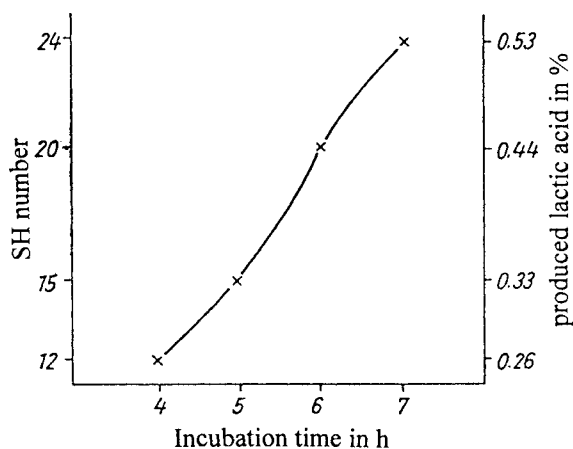


Figure 6./5 Optimal acidification curve during the preparation of butter culture

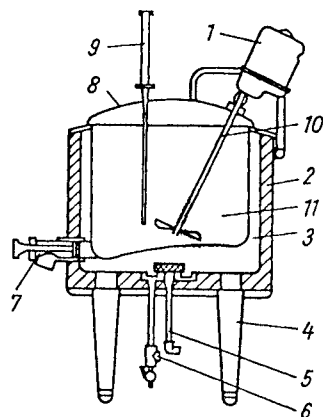


Figure 6./6 Tempering vessel for the preparation of butter starter culture

(1) Motor for stirrer (2) Insulated shell (3) Inner shell for heating (4) Feet (5) Steam inlet with distributor (6) Water inlet and outlet (7) Valve for culture sampling (8) Lid (9) Thermometer (10) Stirrer (11) Stainless steel vessel for the product

Preparation of the butter culture. A mother culture is incubated under laboratory conditions. From it, an intermediary culture is prepared. For the preparation of the operational culture, the following process is applied:

- a) Selection of whole milk or skim milk, which is free from any inhibitors, and heat treatment
- b) Reheating to 90–95 °C and holding for 25–45 min in an incubation tank or tempering vessel (Figure 6./6)
- c) Cooling to 18–21 °C (acidification temperature)
- d) Inoculation with 0.5–1.0% of intermediary culture or mother culture with a good stirring
- e) Monitoring of the acidification process (SH value 30–32 after 18–20 hours)
- f) Stirring of the culture and addition of cream
- g) Cleaning of the starter tank and steam sterilization

Quality evaluation. Quality assurance consists of a daily check on taste, flavor, appearance and acidity. Periodically a microbiological check has to be performed on coliform bacteria, yeast and mould as well as other germs, especially spoilage-causing organisms.

If the culture suddenly fails or if there is a loss of activity, this can be attributed to bacteriophages. Bacteriophages can be classified as a virus¹, which penetrate, inactivate and dissolve the bacterial cell (lysis). In such a situation, fresh cultures are required. The sensorial requirements are as follows:

Appearance: Smooth, gel-like precipitate, slight serum deposit is possible

Smell: Clean, acidic, slightly aromatic (butter flavor)

Taste: Clean, lactic acid, aromatic (butter taste), slightly refreshing

6.2.3. Buttering

The classic process is the buttering process, it will be described hereafter with unit operations such as:

- a) Butter formation
- b) Postbuttering
- c) Kneading (mixing).

Each unit operation occurs sequentially and continuously in a buttering machine or discontinuously (periodically, batch-type process) in a butter churn.

In comparison to the batch process, continuous buttering has advantages from a technological and economic point. Because of the high level of automation and good design of the installations, good and stable butter quality can be achieved with low fat losses, which was not possible with the former batch-type butter churns. Butter churns are used today for only small capacity lines and certain specialties. Therefore only the continuous process will be described.

6.2.3.1. Butter formation

During butter formation, cream is converted into butter. With a certain amount of mechanical energy, fat—which is emulsified in the cream—is agglomerated into larger lumps (butter granules) visible to the eye. The aqueous phase turns into buttermilk. This means also a conversion of the emulsion type, i.e., we have a phase reversal.

- The fat-in-water emulsion (cream) changes into a water-in-fat emulsion (butter).

Fat now becomes the continuous phase of the new type of emulsion. In continuation of this process, the highest possible degree of distribution of the now dispersed water must be achieved (with parts of the nonfat dry matter), and at the same time a smooth consistency and texture of the fat structure must be developed.

Processes during the fat globule agglomeration. In the buttering machine, cream is subjected to strong mechanical forces. Parts of the fat globule membrane are removed—due to the high shear stress—until such time, that the fat crystals penetrate and destroy the membrane. At the same time the fat globules are pushed together in the space between the

¹ Viruses are small organisms with a diameter of 200–250 nm, consisting mainly of genetic material and require a host

beater and the wall of the buttering machine (Figure 6./7a), a discharge of liquid fat passes through the membrane, and the fat globules agglomerate (Figure 6./7b). Solid fat, intact fat globules and serum droplets are entrained, and due to the tumbling movement of the liquid, a grainy product with nearly the same grain size (sort of pellets) are formed (Figure 6./7b). These pellets consist of many small fat grains and are called butter grains.

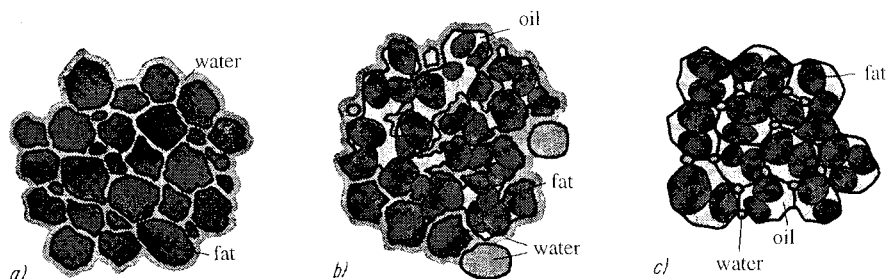


Figure 6./7 Conversion of cream into butter by fat globule agglomeration

a) Cream b) During buttering c) Butter

Factors in butter formation. The dimensions of the buttering cylinder are constant, and time is also constant due to the residence time in a continuous process. Butter formation has to take place within this time/distance envelope; i.e., all the fat of the cream has to agglomerate.

To what degree this objective has been achieved is shown in the buttering overrun, which corresponds to the fat content of buttermilk. This fat transition into buttermilk, based on the fat content of cream, is expressed as a relative fat loss.

- The relative fat loss in % indicates, how much of the total fat input from cream has not been included by butter. It should not exceed 0.6%.

The relative fat loss can be calculated as follows :

$$RFL = \frac{(80 - 0.991 \times f_{Cream}) \times f_{Buttermilk}}{f_{Cream}}$$

RFL	relative fat loss %
f_{Cream}	fat content of cream %
$f_{Buttermilk}$	fat content of buttermilk %

Butter formation is influenced both by the quality of the cream and by the buttering machine; i.e., mainly by the buttering cylinder. Apart from optimal cream ripening, the following parameters of cream influence butter formation:

- Fat content; a high fat content will lead to quick butter formation.
- Buttering temperature; a high temperature will lead to quick butter formation.
- Ripening degree, optimal pH.

In the buttering machine, butter formation happens within 5–15 seconds. The residence (buttering time) is influenced by factors such as:

- a) Rotational speed of the beaters (10–40 m/s), variable with the shaft speed (low speed → longer residence time)
- b) Diameter and length of the cylinder
- c) Gap, i.e., radial distance between beater and cylinder (1–2 mm)
- d) Flow rate of the cream (high flow rate → short residence time)

6.2.3.2. Postbuttering, separation of the buttermilk

In this operation, almost complete separation of the blend buttermilk/butter should be achieved, and the smaller (rice grain to corn grain sized) butter grains should be attached to each other. The level of nonfat solids in the finished product depends on the efficiency of this separation process.

- The higher the percentage of buttermilk and the larger the grains, the higher is the nonfat solids (mainly protein) content in finished butter.

At the same time, about 90% of all microorganisms found in cream are removed.

Postbuttering and separation processes. The butter grains/buttermilk blend passes through a chute into the postbuttering and separation cylinder. In the machine shown in Figure 6./9 chilled buttermilk ($T \leq 2$ °C) is returned to the first third of the cylinder in order to remove the heat, due to friction during butter formation. To achieve the desirable fat hardness, the blend is chilled to 2–7 °C; and thus postbuttering is optimized. In the second part of the cylinder, which is designed as a sieve drum, buttermilk is separated and at the same time postbuttering continues due to the rotation of the butter product.

Washing of butter. Washing is done to remove the buttermilk particles that still adhere to the buttergrain, even when the buttermilk has been separated. This further reduces the level of dry matter and reduce the risk of microbial spoilage. Washing, however, reduces the acid and flavor content, resulting in a reduction of the organoleptic quality of butter.

Washing process. In continuous installation, the last third of the postbuttering cylinder is designed as a washing station, where butter grains (after separation of the buttermilk) are sprayed with water. Due to the large butter agglomerates in this section and the short residence time, the washing effect is low.

Further, the growth of residual microorganisms depends not only on the amount of available nutrients but also on the size of the emulsified water (serum) droplet, i.e., water distribution. As a very effective water distribution is achieved with buttering machines, washing can be eliminated in many cases. For a batch-type buttering process, washing is required in many cases due to the lower degree of water distribution.

6.2.3.3. Kneading (mixing)

The term “kneading” for this operation has been adopted from the batch-type process. In continuous installations it consists more of a pressing and blending process, having the following objectives:

- a) Conversion of the loose butter grains into a homogeneous, compact mass

- b) Highest possible degree of distribution for serum (or water) with a droplet diameter < 10 μm to reduce the risk of microbial spoilage
 - c) Standardization of the fat or water content
 - d) Eventual addition of acidification concentrates, salt solutions or herbs and water
- The shelf life of butter depends mostly on a homogeneous water distribution and the water droplet diameter.

On the other hand, the risk of an enzymatic spoilage is increased by the distribution of the water droplets, as fat-splitting enzymes have a larger surface for attack. This is the case only when the enzymes have not been fully inactivated due to insufficient heating of cream. Normally, cream heating is sufficient for inactivation; therefore the requirement is valid:

- Water and serum droplets must be distributed as finely as possible during kneading.

Kneading process. Butter grains, together with buttermilk residues, pass via a chute into the first section of the two-stage and upward-inclined kneading installation. Buttermilk is collected in a sump, due to the inclination of the machine, and the butter grains are picked up by the screw of the pressing device. Buttermilk is discharged. Buttermilk is pressed from this compact butter mass until the desired final water content is obtained.

- Water content is the amount of water incorporated in butter, which cannot be removed by mechanical means.

Butter has been pressed “dry”; i.e., finely distributed water will not exude from the finished product.

In the first mixing zone, an even distribution of water takes place. At the same time, additions such as starter distillate—lactic acid bacteria blends (e.g., when making lightly acidified butter), herb concentrates for herb butter, or colorants can be made.

A vacuum treatment of the butter mass is very advantageous for the fat structure, consistency, and optimal hardness, using a vacuum of 0.4–0.25 bar. The air content of butter, which can be at 4–7% without deaeration, can be reduced to 0.25%.

Normally the vacuum section is placed between two mixing sections. The homogeneous butter mass leaves the first mixing section, passes through a multiport disk, and enters the vacuum section in the form of numerous small strands, thus exposing a very large surface to the vacuum.

In the second mixing section, the final distribution of the serum droplets takes place, and the homogeneous structure is finished. In this section, the final water content can be adjusted to a small degree by adding water.

Buttering machines of an older vintage and with a smaller capacity can have the pressing and mixing process take place in one section; they are called single-chamber kneading machines.

Control of the water content. The basic water content can be adjusted by the cream flow rate and beater velocity; the final water content in butter can be adjusted by a water dosing installation.

- The higher the flow rate, the lower is the basic water content.
- The faster the beater speed, the lower is the basic water content.

Good mixing of water can be achieved with dosed quantities up to 7%. At higher dosed quantities, the distribution is no longer homogeneous, resulting in water separation.

Rapid and continuous water level control can be done by using the dielectric constant or a refractometer. Data are shown digitally, and can be recorded on a chart or can be processed in a computer for automatic control of the water content. For this purpose other parameters of the cream have to be measured, such as pH, fat content, temperature, flow rate and beater speed, in order to derive control parameters for the beater speed and flow rate.

6.2.4. Salting of butter and addition of herbs

Salting of butter and the addition of herbs for the manufacture of herb butter or addition of other spices and taste-imparting foods serves to increase the variety of foods. The purpose of salting is not extension of the shelf life, due to the small amounts incorporated.

In contrast to other countries, where butter has a salt level of 1–2%, in Germany the butter is salted only lightly. Salt content normally is in the range of 0.3–0.5%. The salt used must comply with the following requirements:

- a) Pure salt, NaCl content minimum 95%
- b) Crystalline, no lumps
- c) Free from dirt and heavy metal contamination
- d) Free from harmful and pathogenic microorganisms

Salt addition. In continuous buttering machines salt is added the form of brine by using the water feeding system or dosing device of the mixer. A brine solution is prepared one day before being utilized and salt is dissolved in a ratio of 0.5:2 (salt to water); the solution is boiled, cooled and stored at low temperatures until being used.

Herb addition. Herb butter can be made with the following formula: For 1 ton of butter about 42 kg of a herb blend (75% chives and parsley, 25% dill) and 0.25 kg garlic powder are prepared. The herbs are blended with a 40% cream, heat treated at 65 °C for 30 min and then chilled to 5 °C. This cream-herb blend is added to the cream (ready for buttering) shortly before the buttering process. An additional 13 kg of salt and, if required 2 kg of sorbic acid for preservation purposes, are added via a dosing device. The resulting buttermilk can be used only for animal feeding purposes.

Normally, herbs in the form of a concentrate together with the salt are incorporated in the butter with a dosing device, which does not influence the buttermilk, and no losses occur.

6.3. Process lines for continuous butter manufacture

With modern process lines for continuous butter manufacture on the basis of the fat globule agglomeration process, products such as sour cream butter, sweet cream butter, mildly acidified butter, unsalted and salted butter can be made. Differences are in the design of the line for the starter culture preparation or dosing as well as in the control system for cream ripening.

Capacities of these lines are in the range of 800–6000 kg/h butter, in some cases even 9000 kg/h. They are controlled by the net flow rate of the buttering machine; its principles are shown in Figure 6./9.

Process. In Figure 6./8 a process line is shown, which does not include the cream ripening, starter culture preparation, CIP system and process control system.

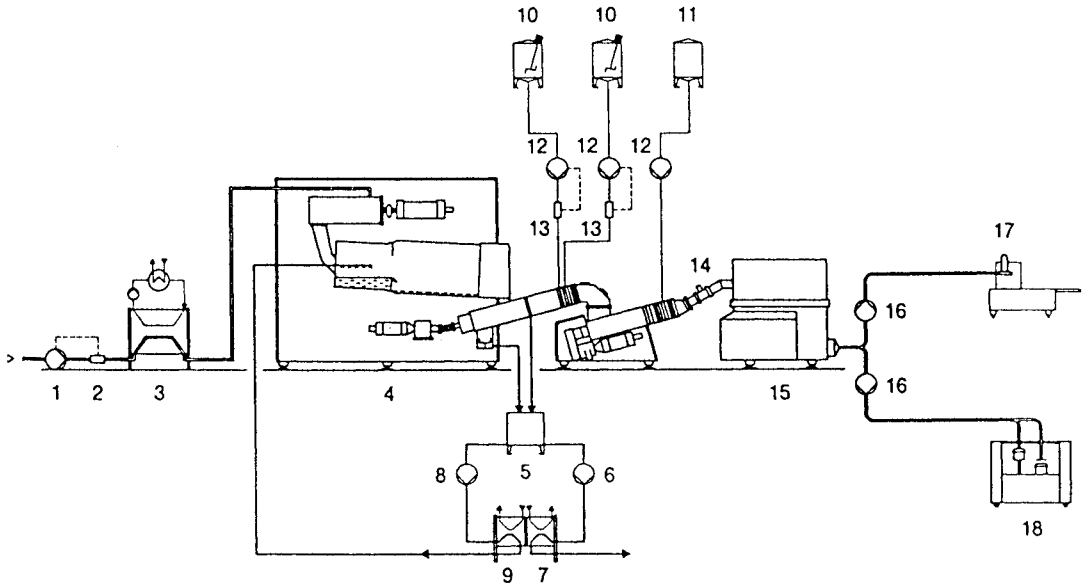


Figure 6./8 Process line for the continuous butter manufacture by the type fat globule agglomeration process

(1) Cream pump with frequency-controlled motor 0–340 RPM (2) Magnetoinductive flowmeter (3) Heat exchanger for cream (4) Buttering machine type BUD (5) Buttermilk reception vessel (6) Buttermilk pump I for buttermilk discharge (7) Buttermilk chiller (8) Buttermilk pump II for recirculation (9) Buttermilk chiller for recirculated buttermilk (10) Tank with stirrer for additives in mixer I (11) Tank for water dosing in mixer II (12) Dosing pump with frequency-controlled variable drive motor (13) Magnetoinductive flow meter (14) Position for water content sensor (15) Butter trolley with transport screw, $V=5000$ l, net quantity 3500 kg butter (16) Butter pump with plastic rotors (17) Butter packing machine for retail butter with integrated case packer and, if required, palletization device (18) Double-head carton filler for 25-kg butter cartons

The ripened cream is transferred with a cream pump (1) from the cream vessel via a plate heat exchanger (3) into the buttering machine (4). A flowmeter (2) monitors the flow exactly and thus controls the flow rate of the cream pump. This permits adequate control of the ingoing cream flow, so a level controlling buffer tank can be eliminated. The flowmeter signal is also used to control the dosing quantities.

Cream is brought up to the buttering temperature in the plate heat exchanger (3). It is designed in such a way that the pressure drop and temperature difference between cream and heating medium are kept as low as possible. In case of a process interruption, the cream temperature can be kept constant in a cooling section, and thus temperature excesses, which can disturb the process, can be avoided.

The main process takes place in the buttering machine (4 and Figure 6./9). Cream goes into the buttering cylinder, where a variable-speed driven beater system incorporates mechanical energy, so that buttering is finished at the end of the cylinder. A part of the heat is removed with the help of an ice water chiller (0–1 °C).

The butter grain/buttermilk blend then passes via a chute into the postbuttering cylinder, which is separated into three sections with the help of annular baffles. In the first third of the cylinder the butter is sprayed with chilled buttermilk in order to remove more heat from the butter grains. This serves the purpose that the exit temperature of butter corresponds to the cream inlet temperature, which is advantageous for further treatment and final quality. Cooling of this recirculating buttermilk, which is taken away from the buttermilk collecting vessel, is done with a plate heat exchanger (9) and the transfer is done with a pump (8).

The butter grain/buttermilk blend passes over the annular baffles into the sieving drum (separation device). This is part of the postbuttering cylinder, where the agglomeration of the butter grain continues until the butter lumps reach the size of a fist. The separated buttermilk goes into a clarification device, where a rotating drum retains small fat agglomerates from the buttermilk, and is then transferred to the press and added back into the main stream.

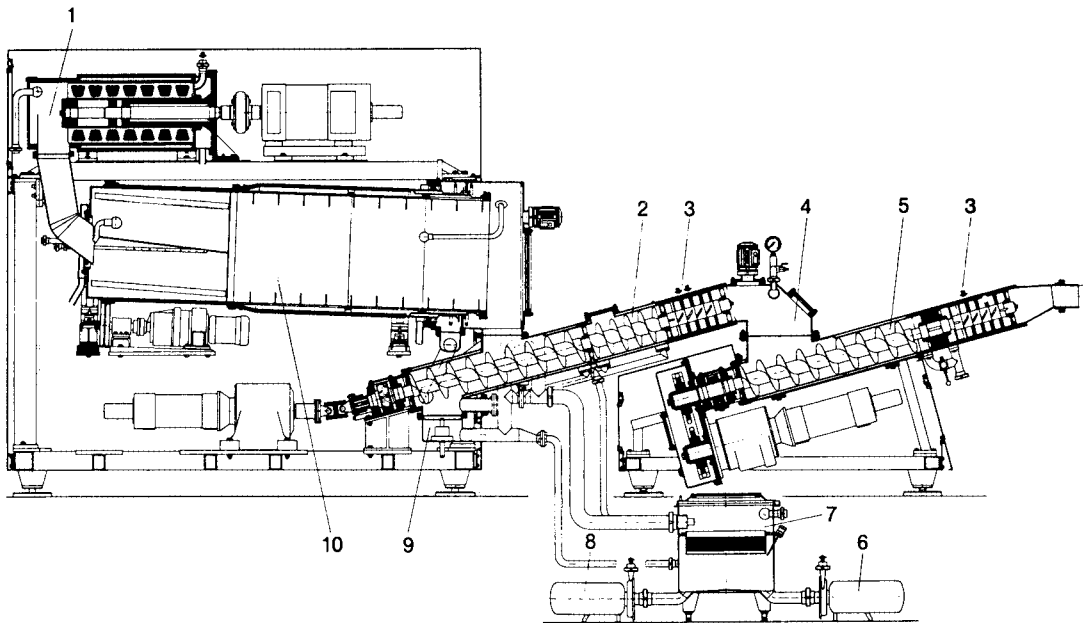


Figure 6.9 Continuous butter making machine, type BUD, net capacity 6.000 kg/h butter (minimum capacity 3000 kg/h), with frequency-controlled varydrive motors

(1) Buttering cylinder with beater system, $n = 0-1200$ RPM varidrive (2) Pressing device with mixing section I, helices and stirrers $n = 0-52$ RPM (3) Dosing connections (4) Vacuum chamber with butter pump, vacuum 0.25 bar (5) Mixing section II, helices and stirrer, $n = 0-82$ RPM (6) Buttermilk pump II for buttermilk recirculation (7) Buttermilk reception tank with sieves (8) Buttermilk pump I for buttermilk discharge (9) Buttermilk clarification device with air-driven motor $n = 100-400$ RPM, air pressure 6 bar, air consumption $16 \text{ m}^3/\text{h}$ (10) Postbuttering cylinder with buttermilk separation device, drum speed $0-30$ RPM

Butter passes through a chute into pressing device I, where it is pressed between two counterrotating helices, and residual buttermilk is extracted. The intensity of the pressing controls the final water content. In the mixing section, butter is reshaped again in a system of chambers, limited by rotating sieves or annular baffles. At the same time, whenever required, dosing of water, acid concentrates and brine takes place, with these products

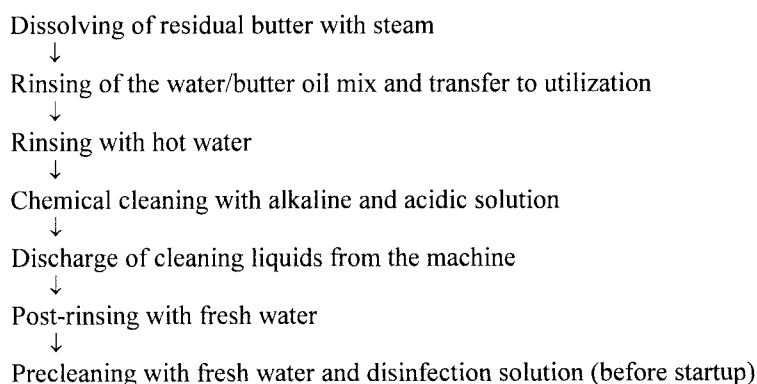
pumped from tanks (10) via a dosing pumps (12) and the flowmeters (13). For control of the dosing process, signals from the flowmeter indicating quantities, volume flow of the products to be dosed, cream fat content and buttermilk fat content are processed, so that at the end a relatively constant butterfat content is achieved.

In the vacuum chamber, which follows mixer I, air is removed from butter, and butter is transferred into mixer II with a pump. Using the same operating principle as in mixer I, fine distribution of water, serum droplets and of other possible additions to butter takes place. Even here a minor correction of the water content can be performed, which is recorded by a sensor at the outlet (14) of the buttering machine. This signal can be used in the automatic control system as well as in a manual control system. Both presses and mixer have an ice water cooling system.

Butter is now transferred into a trough or a silo (15), which is used both as a buffer station and for distribution. In order to avoid a post-crystallization and therefore hardening of butter, the product is kept moving in the trough by two helixes, and a mass of slowly rotating product (drum) with corresponding layering is formed. Butter is then transferred by a butter pumps (16) to a carton filler (18) and/or packing machines for retail butter (19). In order to restrict the extent and the layering of the "butter drum" and therefore counter possible quality degradation of the butter structure, its dimension is used a signal to control the flow of butter into the filling machines.

The operating principle of a packing machine for retail butter is shown in Figure 6./10, and in Figure 6./11 the operating principle of a case packer is shown. If there are sufficiently large capacities, palletizing units for retail butter and bulk butter can be installed.

Chemical cleaning (CIP, cleaning-in-place). At the end of the production cycle, the entire production line must be cleaned chemically and disinfected. For this activity, two circuits are connected. One circuit connects to the cream ripening tanks, pipelines and pumps; a second circuit connects to the buttering machine. The CIP process basically follows the operation as described in Chapter 11. For CIP of the buttering machine, the following specific operation is used (after production shut-down):



For the CIP process, the buttering machine uses a system of CIP of pipelines, which is shown in Figure 6./12. The entire CIP process is run by an automatic program controlling the valve actuation, RPM control, time for dosing of cleaning liquids, temperatures and others.

All the process operations such as startup, production, shut down and CIP are shown on a board in form of a flowsheet, indicating all the data. Another form of representation is on computer monitors.

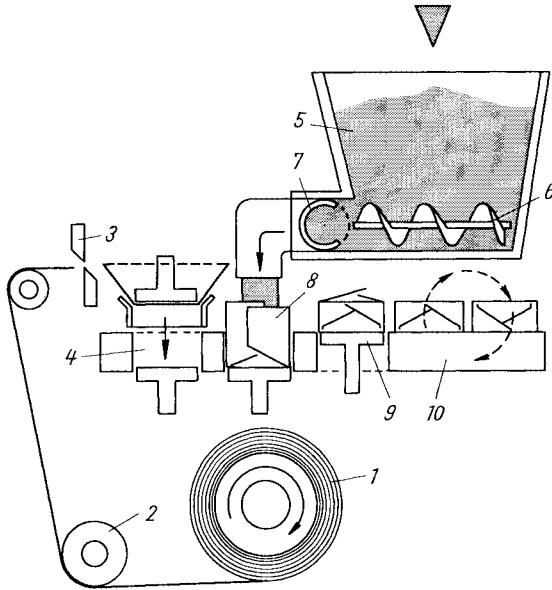


Figure 6./10 Working principle of the form, fill and seal machine, type PA 1 for retail butter

(1) Packing material coil (2) Compensation rollers (3) Cutting device (4) Folding funnel (5) Product trough (6) Transfer helix (7) Dosing chamber (8) Filling station (9) Conveyor belt

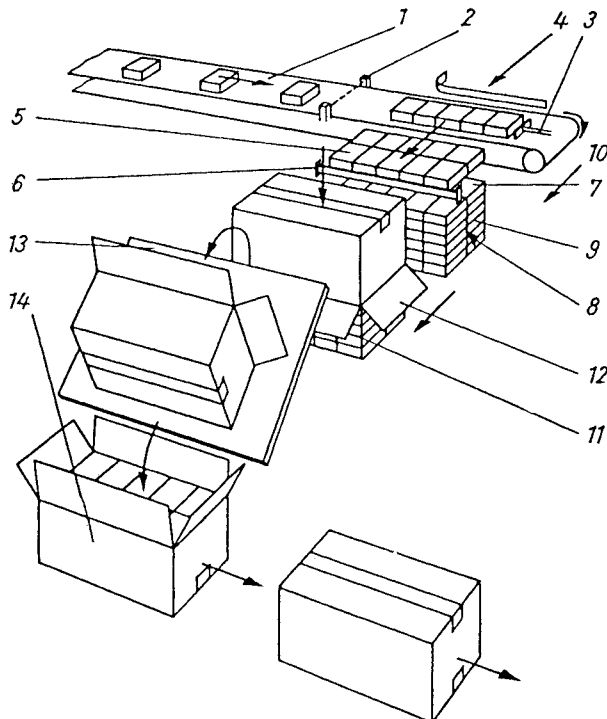


Figure 6./11 Working principle of a case packer for retail butter

(1) Conveyor belt in (2) Light sensor (3) Pressure switch (4) Pushing device for five 250 g cakes (5) Layer with ten 250 g cakes (6) Motion sensor with switch (7) Descending platform (8) Sheet for vertical alignment of a layer with butter cakes to form a square stack (9) Stack with 60 butter cakes (10) Pushing device (11) Magazine (12) Preerected folding cartons (13) Chute (14) Packed folding carton

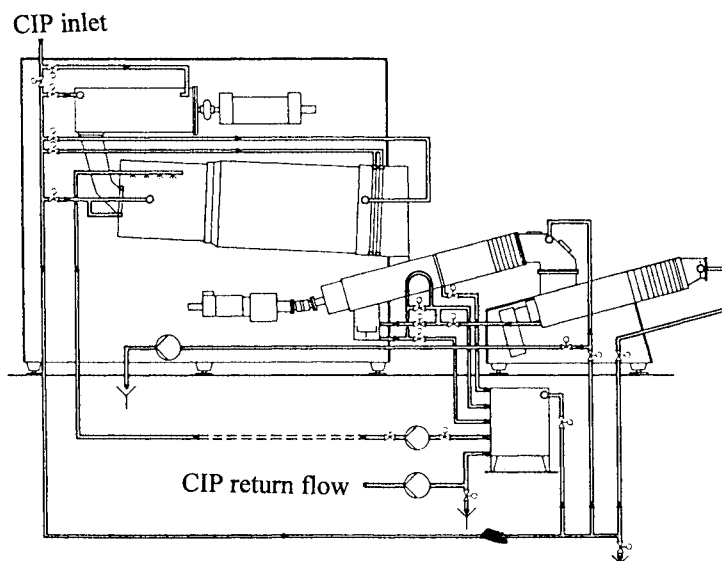


Figure 6./12 CIP cleaning system in a buttering machine

6.4. Batch butter manufacturing

In batch-type processes, butter formation is also based on the fat globule agglomeration process (see Section 6.3). A specific characteristic is the utilization of a butter churn, where a defined amount of cream is subjected to sequential unit operations or periods such as butter formation, separation of the buttermilk, washing and kneading into butter. A churn can be refilled only when the butter has been removed. This relatively time-intensive process is used in case of smaller capacities, at farm dairies, for example.

Process. After the churn (which has been cleaned and sanitized the previous day), has been sprayed on the inside with cold water—in order to form a thin layer of water on the interior surface and thus avoid sticking of butter—ripened cream is pumped into the churn. The filling volume V_{Cream} depends on the volume of the churn V_{Churn} and the cream fat content f_{Cream} as per the formula:

$$V_{Cream} = \frac{V_{churn} \cdot 10\%}{V_{Cream}}$$

Butter formation takes place within 30–45 min of axial rotation at a speed of about 20 RPM. When the butter grains have reached the size of peas, the churn is stopped, the buttergrains float on the buttermilk, and the buttermilk is discharged from the bottom of the churn (Figure 6./13). The butter is washed with water at 2–3 °C, and the water quantity depends on the number of washing cycles:

- a) Single washing step—water is equal to the amount of cream
- b) Double- or triple-washing step—water is equal to one-third the amount of cream in the first washing and two-thirds the amount of cream in the second and third washing.

The washing operation is done a speed of 3–6 RPM, the butter forms a compact mass due to a rolling movement, shearing, pushing and pulling (Figure 6./14) and water is distributed evenly.

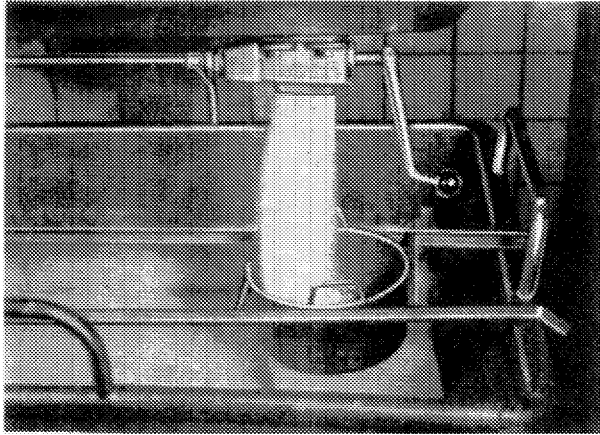


Figure 6./13 Discharge of buttermilk from a churn

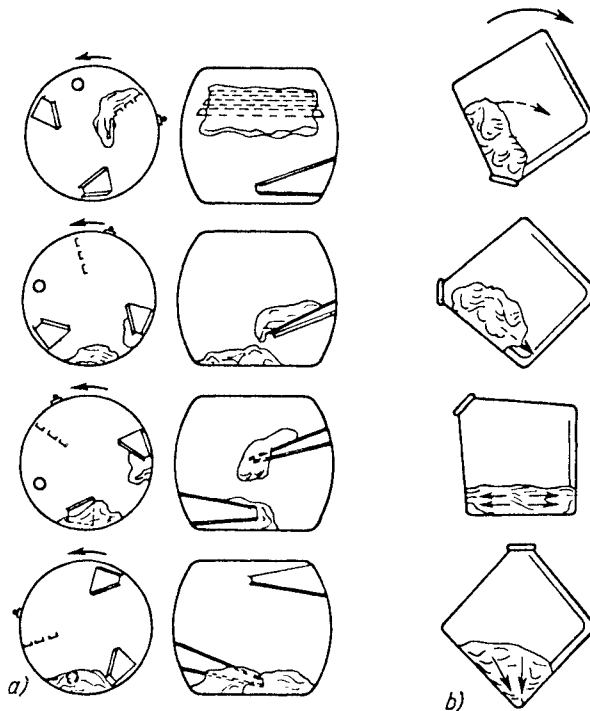


Figure 6./14 Movement of the buttermilk mass in the churn during kneading

a) With baffles b) Without baffles

Butter churns can be classified as those having installed baffles (either beaters or grid or pairs of rotating rollers) and those without baffles. This determines the design of the different geometric forms (Figure 6./15).

6.5. Fat concentrate chilling process (separation process)

In this process cream is obtained by a single or double concentration using a separator, and the fat content is then standardized. Phase reversal is achieved by chilling the fat concentrate in scraped surface chilling units leading to a multistage fat crystallization. This results in degradation of the boundary layer tension between the phases and porosity or partial destruction of the fat globule membrane. By adding stabilizers or emulsifiers e.g., gelatin, which further reduces the boundary layer tension and also binds water, products such as reduced-fat butter, low-fat butter, and even butter with fat content < 39% can be manufactured with this process.

Apart from the low fat contents which can be obtained with this process, it has other advantages, such as:

- a) Completely enclosed and hygienic process
- b) Extremely low fat losses
- c) Water distribution with a droplet diameter of 5–7 μm
- d) Formation of a soft product with a smooth consistency

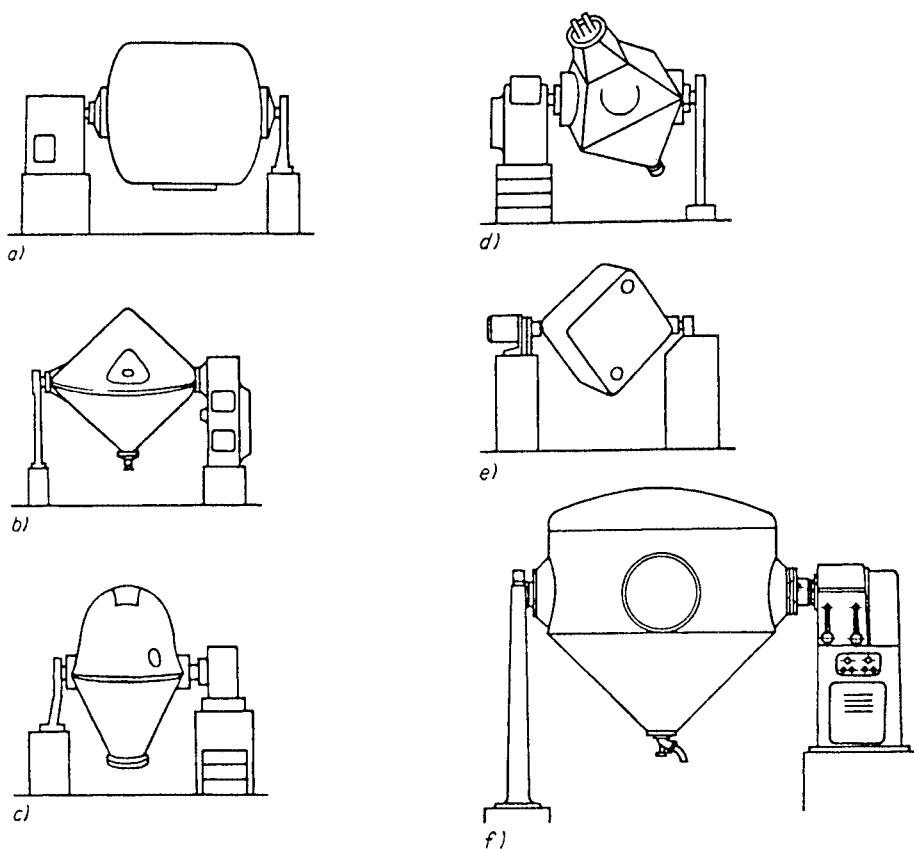


Figure 6./15 Shapes of butter churns

- a) Cylindrical (barrel) form
- b) Double cone form
- c) Conc-ellipsoid form
- d) Octahedron form
- e) Cubic form
- f) Ball form

Process. As shown in Figure 6./16, standardized, pasteurized and chilled cream (16–18 °C) is pumped into a cream ripening tank (1). A pump (5) doses 1–3% starter culture from the tempering tank (6) to initiate the acidification. For color improvement, 0.03–0.05% of butter colorant can be added to the cream. After reaching a pH of 6.2, cream is chilled to 6 °C. During the ripening process (16–18 hours) the boundary surface tension is reduced by fat crystallization, and the fat globule membranes become porous. Further, the pH is 5.5–6.2, depending on the acidity level.

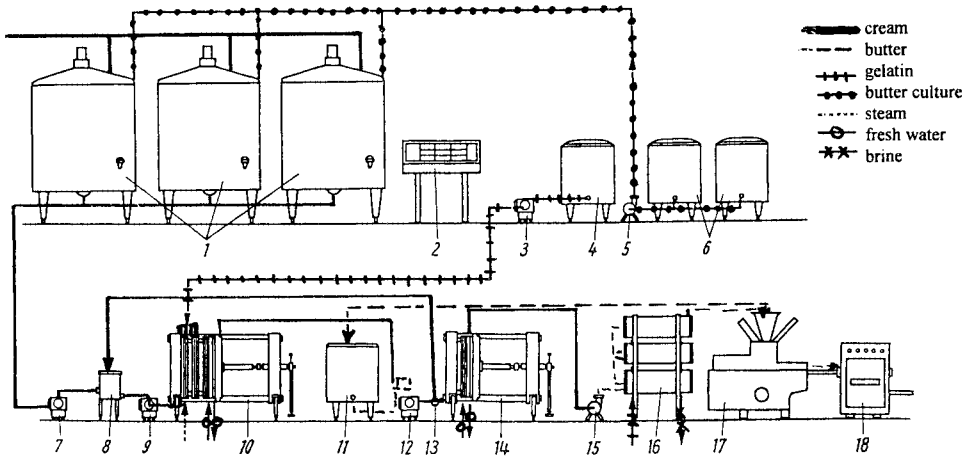


Figure 6./16 Process line for the manufacture of fat-reduced milk spreads

(1) Cream ripening tank (2) Control panel (3) Screw pump (4) Tempering tank for gelatin preparation (5) Centrifugal pump (6) Tempering tank for culture preparation (7) Screw pump (8) Buffer tank with floating device (9) Screw pump (10) Plate heat exchanger (11) Circulation tank for remelting of butter and startup (12) Piston pump (13) Safety valve (14) Plate heat exchanger (15) Emulsion pump (16) Kneading cooler (17) Cup filling machine (18) Tray packer

Once the ripening is complete, cream is transferred with a pump (7) via a buffer tank (8) and another pump (9) through a plate heat exchanger (10) and is heated to 95 °C. Thereafter 0.6–0.8% gelatin in form of a 20–25% solution (temperature 60–70 °C) can be added to the hot cream from a tank (4). The gelatin solution is prepared the day before for a better rehydration. The final fat content is standardized by adding gelatin solution, water or skim milk. Once the additives have been incorporated, the fat content must be that of the finished product.

The cream is then cooled down to 40 °C and transferred to a piston pump (12). Due to the lower flow rate of the piston pump (vs. the centrifugal pump (9)), a return flow develops, which goes via a safety valve (13) into a buffer tank (8). The piston pump transfers the cream to a plate heat exchanger (14), where it is cooled to 10–14 °C (by using ice water) and reaches a “demulsifying pump” (15). In this specialized pump, butter formation takes place, i.e., a phase reversal. The butter then reaches the triple-cylinder scraped-surface kneading cooler (16), where the water-in-fat emulsion is stabilized and plastified by intensive kneading. Butter is discharged at 15–20 °C and is transferred straight to the funnel of the filling machine (17) in the form of a highly viscous mass; it is placed there in preformed cups, which are closed and assembled for transport. The fat solidifies by

post crystallization in the cup and is turned into a solid, plastified mass with a typical consistency.

During start-up of the plant or interruptions, the butter flow is returned via the melting device (11), is melted, reemulsified and returned to the process. All additions (of cream and additives) are stopped automatically.

6.6. Indirect biological acidification process (IBA)

This process is characterized by the utilization of sweet cream for the production of acidified butter (in Germany mildly acidified butter), which results in nonacidified buttermilk. During the kneading of butter, a special acidification culture and sometimes a starter distillate (obtained from special cultures) are added, and the typical character of a sour cream butter develops.

The most widely known process for this type is the NIZO process (derived from the Netherlands Institute for Dairy Research at Ede). The advantages of this process are mainly the elimination of the difficult-to-control biochemical cream ripening and the fact that the nonacidified buttermilk has wider application and can be used with fewer problems. The process is similar to the continuous process described in Section 6.3.

Culture preparation. A culture concentrate (CC) is obtained by ultrafiltration from a *Lactobacillus helveticus*/whey culture and is adjusted to pH 3 and 0.5% of this clear, low-viscosity and very acidic concentrate is added to butter.

A second flavor-developing special culture 4/25 is required, containing 16% dry matter and 100 mg diacetyl/kg. In a phage-proof vessel (tank) this culture is cultivated, blended with the CC culture in the ratio of 3:2.2, and for 20 min air is incorporated. This is supposed to enhance the flavor development and 1.3% of this blend are added to butter.

6.7. Fat emulsion process

In this process, butter formation is based on the destruction of the fat globule membranes and on the fact that at temperatures above the fat solidification, free fat develops. This fat is concentrated in separators up to the desired fat content and is then chilled, thus forming a solidified fat concentrate (butter). An acidification culture can be added, if required, into this butter, and after a few days a sour cream butter flavor develops.

For butter manufacture based on the butter oil emulsification process, two processes are of importance, which are used mainly in the United States:

- a) Gold'n flow process (Cherry-Burrel process)
- b) Creamery-package process (C.-P. process)

6.8. AMF manufacturing process

If butterfat is not used for direct consumption but is used for processing in other food, it can be advantageous to store this fat in the form of anhydrous milk fat (water-free milk fat). Such anhydrous milk fat (also called butter oil, in India known as ghee) can be stored for several months at temperatures $<10^{\circ}\text{C}$ without any quality deterioration.

Anhydrous milkfat has many applications, such as manufacture of recombined milk, sterilized milk and evaporated milk, chocolate and other fat-containing sweets, ice cream and biscuits.

According to the norms of the FAO/WHO, anhydrous milk fat should have a minimum fat content of 99.8%, and the water content should not exceed 0.1%. "Butterfat" should have a minimum fat content of 99.3% with a maximum water content of 0.5%. Anhydrous milk fat can be manufactured as follows:

- a) Processing of deepfrozen and normal butter
- b) Processing of cream
- c) Separation of pure milkfat into fractions with a high and a low melting point (fractionation)

The latter two processes are described hereafter:

Processing of cream. A process line is shown in Figure 6./17, where cream with a fat content of 30–40% goes to a buffer tank (1) and is transferred with a pump (2) into a plate heat exchanger (3), where it is heated to 95 °C (mainly for lipase inactivation). Cream is cooled to 55–58 °C by passing through a heat recovery section.

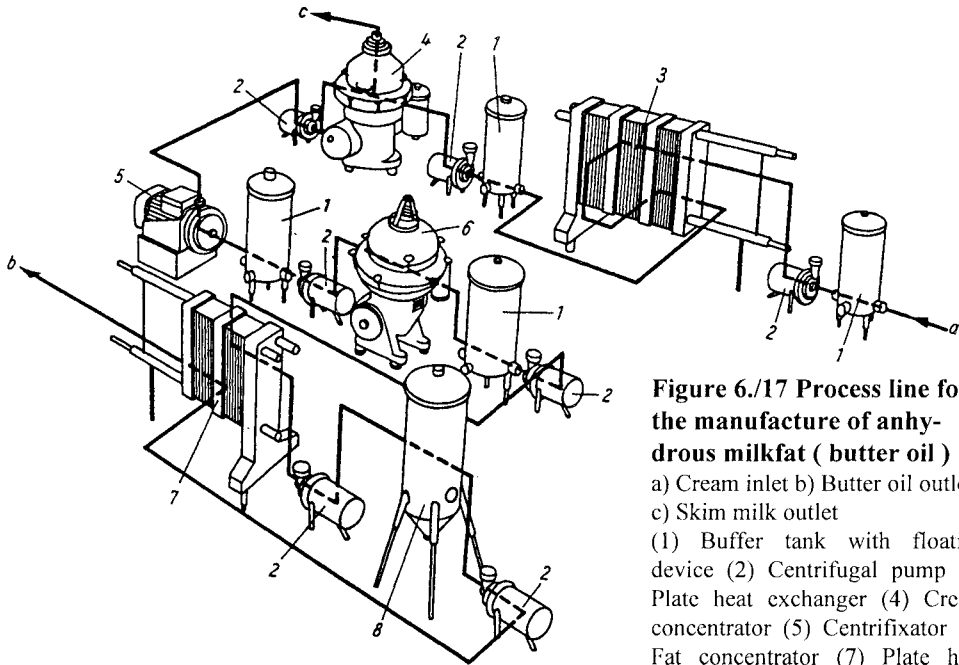


Figure 6./17 Process line for the manufacture of anhydrous milkfat (butter oil)

a) Cream inlet b) Butter oil outlet
c) Skim milk outlet

(1) Buffer tank with floating device (2) Centrifugal pump (3) Plate heat exchanger (4) Cream concentrator (5) Centrifixator (6) Fat concentrator (7) Plate heat exchanger (8) Vacuum drier

Cream is then concentrated in a separator (4) to a fat content of 70–75%, and the skim milk is discharged. Cream then passes through a centrifixator (5), where the emulsion is broken and the fat globule membranes are destroyed, and then reaches a special separator (concentrator) (6), where the free fat (butter oil) is adjusted to its final fat content. The aqueous phase with still intact fat globules is then returned via a buffer tank to the separator (4) and again passes through the entire process. Fat is reheated to 80 °C in the plate heat exchanger (7), dried to 0.1% moisture content in a vacuum drier (8) and cooled in a plate heat exchanger (7).

Fat fractionation. In this process, the anhydrous milkfat or butterfat is separated into fractions of triglycerides with a high melting point (stearin fraction) and a low melting point (olein fraction). These different fractions can be used to adjust the consistency of

butter, if this is legally permitted, or can be used in many ways in the manufacture of foods.

Process. In the process line as shown in Figure 6./18, butterfat is transferred to the crystallization tank (1) at a temperature of 45–50 °C, where due to controlled cooling to 20–24 °C, the high-melting-point triglycerides are crystallizing within 6 hours and settle. Before this treatment commences, a surfactant (in aqueous form) is added to the fat in order to facilitate the separation of the crystals from the liquid fat. A pump (2) transfers the fat into a mixer (3), where the larger crystals are grown to an easily separable size, and into another mixer (4), where intensive blending with surfactant takes place. This blend, consisting of the phases light liquid (free oil), heavy liquid (with the surfactant) and heavy fat crystals, is then transferred to a separator (5). The pure free oil is discharged at light-phase discharge, and the crystals are discharged together with the surfactant through the heavy-phase discharge outlet. Crystals and surfactant are heated in a plate heat exchanger (7) to melt the crystals and are then separated in a separator (8). The surfactant is then returned to a blending unit (4).

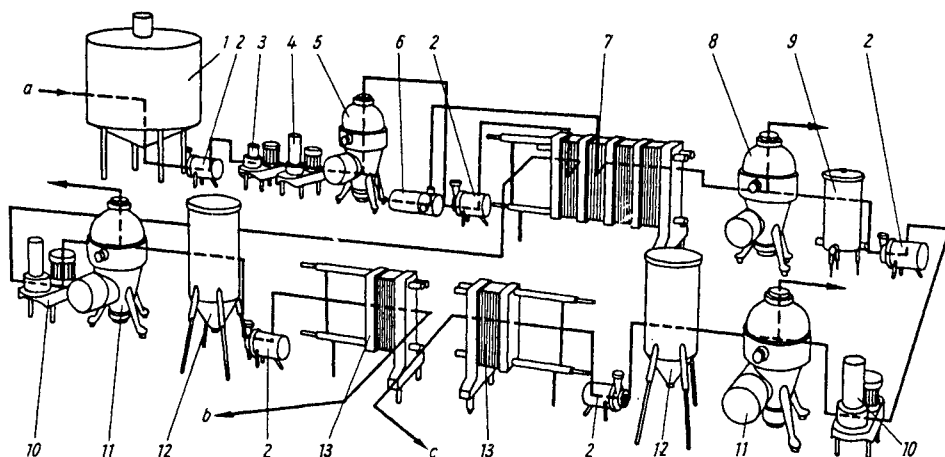


Figure 6./18 Process line for fat fractionation

a) Fat inlet b) Fraction with a higher melting point c) Fraction with a lower melting point (1) Crystallization tank (2) Centrifugal pump (3) Mixing stage 1 (4) Mixing stage 2 (5) Separator (6) Dosing pump (7) Plate heat exchanger (8) Separator (9) Buffer tank with floating device (10) Wash water mixer (11) Wash water separator (12) Vacuum drier (13) Plate cooler

The purified fractions of high-melting point and low-melting triglycerides then pass through separate and parallel processing steps. First, wash water is mixed into the fraction (10), and taken out again in the separator (11); then a vacuum drying takes place (12), where a moisture content of <0.1% is obtained, and finally a cooling in a plate heat exchanger (13). Capacity of such a process line is about 1500 kg/h of pure anhydrous fat, of which 1050 kg has a high melting point and 450 kg has a low melting point.

6.9. Mixed fats products manufacturing process

For mixed fat products (see Overview 6./1) the following effects can be obtained:

- a) Improvement of the application characteristics, e.g., spreadability at refrigerator temperatures
- b) Development of new bread spreads with milk milkfat as an alternative to spreads made from pure vegetable fats (margarine)
- c) Reduction of energy content and increase of the dietetic value of the product
- d) Extension of the product range

The manufacture of these mixed fats products is done with a specifically designed process, and vegetable or other animals fats are replaced by 5–25% milkfat. Consistency is improved by the percentage of vegetable fats, the melting point is reduced, and very good spreadability is achieved at refrigerator temperatures. By adding stabilizers and emulsifiers (0.1–0.5%) and increasing the protein content to 5–7%, the total fat content can be reduced to less than 40%, and the energy content can be reduced significantly.

Raw materials are selected as a function of a formula and finished product:

- a) Anhydrous milkfat, butterfat or cream with different fat contents
- b) Vegetable oils (soy oil, sunflower oil and others) and fats as well as hard animal fats
- c) Dairy protein from milk powder, coprecipitates or skim milk
- d) Water
- e) Starter cultures, organic or inorganic acids
- f) Flavors (diacetyl), if the milk phase has not been acidified by starter cultures
- g) Salt (for salted fat blends)
- h) Emulsifiers (mainly lecithin and/or mono- and diglycerides)
- i) Gelatin (for water binding)
- j) Colorants

Process lines are designed for a specific process but can be modified, as the processes and subprocesses are very similar. The following characteristic unit operations are encountered:

- a) Preparation of the aqueous phase; i.e., all water-soluble ingredients such as milk protein, salt and flavor are dissolved in water or skim milk and starter culture is added.
- b) Preparation of the fat phase, i.e., melting of the fats.
- c) Dosing and blending of the phases.
- d) Cooling, kneading, plastification.
- e) Packing.

The key unit operation, which controls the consistency of the product, is shock-cooling in combination with kneading, where the fine crystal structure develops. The total cooling distance (provided by either a scraped-surface cooler or a kneader) must be designed in such a way that the required residence time for optimal crystallization is achieved.

6.10. Manufacturing process for cholesterol reduction

Cholesterol is bound to milkfat and can be removed by biological, physical or chemical methods, using the processes described in this section.

Adsorption. Butterfat is liquefied by heating to 70–90 °C and addition of granulated or pulverized activated carbon in a ratio of 5:1 (fat to adsorbent) or 8:1 (fat to activated carbon). The liquid fat is brought into contact with the adsorbent, either in a column or in a vessel, for a certain residence time. Activated carbon can be replaced by specially coated glass, ceramics or plastic. Cholesterol is separated from milkfat by adsorptive binding to reaction particles, as done for colorants and flavors. In order to regenerate the flavor and color, butter flavors and β -carotene are added back to the cholesterol-reduced butterfat (10% of the initial cholesterol remains) at the end of the process.

Extraction. Extraction with cyclodextrins requires melting the milkfat at 40–60 °C, and blending it with a 1–10% aqueous solution of 60% cyclodextrin. This carbohydrate forms a complex with the cholesterol, which is then separated with the aqueous phase from the milk fat. Up to 41% of the cholesterol can be removed in such a process.

Another possibility is extraction from butterfat or milkfat by using supercritical carbon dioxide ($T_{crit} = 31.3$ °C; $p_{crit} = 78.8$ bar) at temperatures of 40–48 °C. With optimal process control (considering pressure and temperature) up to 90% of the cholesterol can be extracted from milkfat in a multistage process without any residues. The cholesterol-enriched fat fraction can be used for purposes other than food manufacturing.

Fractionated crystallization. Here the low-melting-point milkfat fraction (olein fraction) can be separated from the high-melting-point fat fraction (stearin fraction) (see 6.8). The cholesterol content is reduced in the stearin fraction by fractionation but is enriched in the olein fraction. The cholesterol distribution between the fractions is not advantageous, as the low-melting-point triglycerides are softer and more valuable from a nutritional point of view.

Steam distillation. Based on the water solubility of cholesterol, anhydrous milkfat/butterfat is liquefied under vacuum. Cholesterol is extracted in a countercurrent with steam and is enriched in the condensate. This process removes 90% of the cholesterol. Unfortunately, this process also removes flavors.

Enzyme reaction. The enzyme cholesterol reductase can be added so that cholesterol is converted into biologically inactive forms, i.e., nontoxic and nonabsorbable products (e.g., coposterin).

Direct utilization of microorganisms in a free or immobilized form is under consideration, as their enzymes can decompose cholesterol. It may be possible to use genetically modified dairy microorganisms whose enzymes can decompose cholesterol.

6.11. Packaging and labeling of butter

6.11.1. Packaging

Once butter leaves the buttering machine (after intensive mechanical kneading), the “post-crystallization” stage of the fat starts after a certain lag period, and the final structure or consistency of the butter develops and firms up. If there is another mechanical

treatment after this solidification and hardening process, this homogeneous mix is destroyed and the structure breaks down.

- A breakdown is a disruption of the homogeneous butter consistency due to mechanical forces; the finely distributed serum droplets join together into larger droplets and can even be discharged from butter and cause syneresis (a water separation defect).

This phenomenon promotes a favorable growth environment, and spoilage of butter is enhanced. The packaging, which is also carrying all the labeling information, has to comply with the requirements of 5.3.1.

Among the type of packaging we distinguish between retail sales packs (butter brick or cup) and wholesale packs (block butter, barrel). Retail packs are assembled into larger units and are surrounded by plastic shrink wrap. Packaging material serves for covering or wrapping the sales pack and are made of:

- a) Wax paper
- b) Plastic laminate
- c) Combined laminates, made from aluminum foil, which is coated on the product side with plastic or wax paper
- d) Plastic cups made from polyethylene, with a lid
- e) Metal cans

Packing material for transport packs are made of wood (for barrels and boxes) or cardboard (for boxes). Transport boxes are closed with self-adhesive tape or metallic clamps. Packing materials must be stored in dry and dust-free rooms.

Process. Butter must be packed as quickly as possible after leaving the buttering machine. This avoids breakdown of the structure as well as a contamination by ambient air. With larger installations, a buffer silo is placed between the buttering machine and the packing lines; this ensures a continuous supply to the packing lines and an even distribution to each packing line.

- The buffer silo should contain only that amount of butter which is absolutely required to keep the process lines running.

Butter must be kept moving in the silo in order to avoid post-crystallization. Retail packs are processed on form-fill-seal machines with attached case packers; the working principles are shown in Figures 6./10 and 6./11. In larger installations there are also packing machines for transport packs plus devices to stack onto pallets. Block butter is packed in suitable filling machines; a key point during filling is the exclusion of air.

6.11.2 Labeling

Labeling is prescribed by regulations, and in Germany a distinction is made between domestic and export butter. For domestic butter, the markings shown in Figure 6./19 must appear on consumer packs:

- a) Commercial name of type of butter.
- b) Name or company or address of manufacturer, packing plant or distributor within the EU.

- c) List of ingredients, excluding the required dairy components, lactic acid bacteria and the manufactured lactic acid concentrate, made entirely from lactic acid bacteria using only dairy ingredients.
- d) Minimum shelf life; if the indication “refrigerated” is given, then it is assumed to be on the basis of 10 °C.
- e) Type of butter, if the commercial name is used as a commercial grade.
- f) Indicate “salted” if the salt content of the butter is > 0.1%.
- g) For “Deutsche Markenbutter” (butter of a certain quality grade), the indication “Amtliche Qualitätskontrolle des Landes ... Überwachungsstelle” (which is basically a certified quality evaluation by the state) has to appear and the quality logo.
- h) Registration number of the dairy or packing plant.

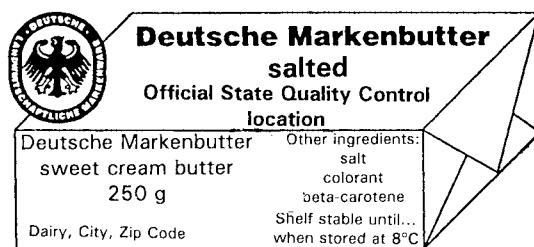


Figure 6./19 Sample for butter labeling

For butter which is not directly used by the consumer, the information in a, b, d, e, and f must be indicated.

Commercial names. The commercial term for butter manufactured in dairies is “butter.” If specific requirements are met, then commercial terms such as commercial grade “Deutsche Markenbutter” or “Deutsche Molkereibutter” can be used. The commercial term for butter manufactured on farms is “Deutsche Landbutter.”

For export butter, the term “butter” is used; in addition, the commercial term of the manufacturing country can be indicated.

6.12. Storage and transport of butter

In general, butter must be handled in dairies, packing plants, wholesale and retail institutions and during transport in such a way that quality is not affected. Cold storage facilities must be used which can maintain a storage temperature of ≤ 10 °C.

Storage. In production and packing plants, the following rule is applied:

- Immediately after packing butter must be stored in a refrigerated storage facility.

Cold storage temperatures must be selected in such a way that, until dispatch, a core temperature of 10 °C is reached. Transport boxes must be stacked in racks or on pallets with a maximum layer height of five boxes of freshly packed butter in order to avoid de-

formations. Simultaneous storage with other products should not be allowed, since it might influence the butter quality.

For long-term storage purposes, butter should be quick-frozen within 12 hours to a core temperature of $-8\text{ }^{\circ}\text{C}$ and then be stored at $-18\text{ }^{\circ}\text{C}$ at a relative humidity of 80–85%. In wholesale and retail storerooms, a storage temperature of $\leq 10\text{ }^{\circ}\text{C}$ and a relative humidity of 80–90 % should be selected. Product shelf life is synonym with minimum shelf life, but this not the beginning of spoilage. If storage conditions are maintained properly, butter can be stored beyond the minimum shelf life indication.

Transport. Butter must be transported in such a way, that it is neither directly nor indirectly adversely influenced, especially by dust, dirt of all kinds, odors, pathogens, or temperature fluctuations. Transport must be done in refrigerated vehicles. Cotransport of other items or materials, as well as persons on the same platform, is not permitted.

6.13. Quality evaluation

Quality evaluation of butter is done in two ways; one is self-control by the dairy and/or packing plant, the other is official evaluation supervised by state authorities. Self-control by the dairies is done with regard to the following aspects:

- a) Quality of milk and cream which are used, especially checks on pH and taste
- b) Water content of butter and, with random samples, fat content as well as salt content for salted butter
- c) Compliance with commercial grade requirements
- d) Type of butter and the targeted pH

From each batch or buttering process (tank, vessel, cream ripener, butter churn) a retention sample must be taken. It is stored at $10\text{ }^{\circ}\text{C}$ and must be checked on the expiration date of the minimum shelf life (valid for retail butter bricks) and on the 14th day after manufacture for block butter. The results of this auto-control must be recorded, and the documents must be kept for at least one year.

For official evaluation, the authorities request samples from the dairies, which must represent the production of an entire day and must be separated according to the types of butter. Samples must be shipped in such a way that the temperature does not exceed $12\text{ }^{\circ}\text{C}$ upon reaching the recipient. The official butter evaluation covers the following aspects:

- a) Organoleptical parameters such as appearance, taste, smell and texture
- b) Water distribution
- c) Spreadability
- d) pH in the serum

The organoleptic evaluation is done by appointed experts from various dairies; the chemical-physical tests are done by employees of the state authorities. The organoleptic evaluation must be done 14 days or at the latest 21 days after requesting the samples, the analysis on pH and spreadability must be done on the eighth day or at the latest on the tenth day after requesting the samples.

Samples which have less than 82% milk fat, more than 16% water or for salted butter more than 2% solids nonfat or a pH in the serum that is not in compliance with the type are not evaluated. Water distribution is rated as 0–5 points. Spreadability is evaluated in

terms of the hardness at penetration, expressed in newtons. The following criteria are applied:

- 0.80 N = 5 points
- 0.81–1.00 N = 4 points
- 1.01–1.20 N = 3 points
- 1.21–1.50 N = 2 points
- > 1.50 N = 1 point

Commercial grades. Butter is classified into commercial grades according to evaluation standards, if the following requirements are met:

- “Deutsche Markenbutter”—butter, made from cream, corresponds to the declared type, contains a minimum 82% fat content and obtains at least 4 points on each requirements a) to c). It must be manufactured in a dairy, which is authorized to manufacture this product
- “Deutsche Molkereibutter”—butter, which corresponds to the declared type, contains a minimum 82% fat, and achieves at least 3 points for each requirement a) to c).

If a butter meets the criteria for Deutsche Markenbutter, then a quality logo can be printed on the pack in addition to the commercial grade. If a butter does not meet the minimum criteria of this commercial grade due to a post-treatment or modification, then it must be reevaluated and must be labeled either Deutsche Markenbutter or Butter.

Butter defects. Butter defects cannot always be precisely identified as to their causes and appearances. The main defects and their causes are given in Overview 6./3.

6.14. Butter yield

Apart from the butter quality, it is of economic interest to know how much fat is converted from milk into cream and finally into butter.

- The butter yield indicates how many fat units are required for the manufacture of one kilogram of butter.

Butter yield is calculated daily by accounting for the fat. This reveals any eventual fat losses. The following actions contribute to a reduction or avoidance of fat losses:

- a) Maintain the targeted fat content.
- b) Reduce adhesion and spill losses during the production and packing.
- c) Use the proper cream treatment.
- d) Select the optimal cream fat content.
- e) Maintain a low basic water content.

Butter yield is calculated according to the formula

$$BY = \frac{FU_{Cream}}{m_{butter}}$$

BY = butter yield
 FU_{Cream} = fat units of cream, used for buttering
 m_{Butter} = mass of butter in kg

Overview 6./3 The most common butter defects

Type of defect	Reason
Taste and smell	
Sour, acidic	Overacidification of cream, insufficient washing of barrel butter
Metallic	Overacidification of cream, high level of metallic ions in washwater, defects on tinned utensils
Yeast-like	Yeast contamination due to improper hygiene
Oily, fishy	Overacidification and/or too high fat content in cream, metal and feeding influences
Malty	Degenerated starter culture, contamination with malt streptococcus
Tallowy, rancid	Oxidation of the fat, especially due to air incorporation
Soapy	Contamination with cleaning agent residues
Rancid, old	Enzymatic fat decomposition, improper and too long storage of butter
Empty, bland	Insufficient flavor development
Water leakage	
Water leakage, exuding water or liquid	Insufficient water distribution during kneading, too long a period between manufacture and packing (breakdown of butter)
Appearance	
Streaky, marbled	Uneven salt distribution, blending of butter
Spots	Contamination with fungus, unhygienic work practices during manufacture and packing
Structure	
Short, brittle	Butterfat too hard, improper cooling profile during cream ripening
Salve-like, greasy	Too much liquid fat in the fat globules, defects in the ripening profile of the cream, too high buttering and kneading temperature

7 Cheese Manufacture

7.1. Terms and definitions

7.2. Classification

7.3. Technology of rennet cheese manufacturing

7.4. Fresh cheese

7.5. Cheese from sour milk quarg

7.6. Cheese with herbs

7.7. Processed cheese

7.8. Packaging of cheese

7.9. Dairy protein products



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7 Cheese Manufacture

7.1. Terms and definitions

- Cheese is made from milk, with the addition of cream, buttermilk and/or whey. This basic raw material is also called cheese milk.
- Cheese consist mainly of casein (the major protein of milk), other milk proteins, fat, other milk components and a certain percentage of water, which is bound.
- Proteins are precipitated by enzymes and/or acidification as well as heat and are separated by suitable processes from the aqueous phase (whey, serum).
- Cheese is most often molded, pressed, salted and has fungal and bacterial culture additions, colorants, herbs and spices and other nondairy ingredients. It is consumed either fresh or at different stages of ripening.

These general descriptions are insufficient to cover the specific characteristics of all individual classes and types of cheese. Therefore other definitions must be used in describing the manufacturing process.

Cheese is one of the oldest dairy products. As long as dairying is done, the objective will be to prepare the highly sensitive protein for human consumption and make it shelf stable. By using different biochemical processes, the relatively tasteless dairy protein is converted into tasty and easily digestible cheese with different flavors. Cheese is rich in essential amino acids and binds large amounts of minerals and vitamins. For example, 100 g of cheese has the following nutritional content:

Energy	1641	kJ (392 kcal)
Protein	23.7	g
Calcium	870	mg
Phosphorus	610	mg
Vitamin A	1740	IU ¹
Vitamin D	13	IU
Riboflavin	0.50	mg
Vitamin B	0.0015	mg

To the consumer cheese is a very nutritional and basically inexpensive food (considering its nutritional value). Cheese consumption makes up for significant “protein deficiencies” in the human nutrition.

7.2. Classification

Worldwide, there are more than 2000 types of cheese, sometimes made by very different manufacturing processes. A classification can be based on several aspects, and is done in different countries according to different criteria. In most cases the classification, definition and manufacturing and quality criteria are controlled by a codex or by law, as done in Germany with the “Käseverordnung” (cheese regulation). A general classification can be made for three major groups:

- a) Rennet or natural cheese. Manufactured straight from milk by using proteolytic enzymes (rennet) and acid, with a more or less pronounced proteolytic ripening process.

¹ International units

- b) Fresh cheese or nonripened cheese (quarg, fresh cheese, white cheese). Its manufacture is similar to that of rennet cheese, but it has a high degree of acidity and is not subjected to a proteolytic ripening process.
- c) Long-life cheese (processed cheese). It is most often made from rennet cheese and is textured by a thermal treatment and made shelf stable.

For another classification into groups and types, different aspects and characteristics can be used, such as:

- a) Type of process (rennet cheese, rennet acid cheese, acid curd cheese, processed cheese)
- b) Type of consistency (hard, semisoft, soft cheese)
- c) Types of milk (cow, sheep, goat, buffalo)
- d) Chemical composition (Ca content in conjunction with pH, dry matter, water, fat)
- e) Ripening process (ripened cheese and nonripened/fresh cheese)
- f) Variations in taste
- g) Type of hole formation (large, medium and small round holes, cracks, irregular holes, no holes)
- h) Surface characteristics (blue fungus or white fungus cheese, smear cheese, skinless cheese)

Another type of classification is into:

- a) Italian hard and grated cheese: Parmesan, provolone
- b) Swiss hard cheese: Emmentaler, Gruyère, Sprinz
- c) English hard cheese: cheddar, Chester
- d) Dutch cheese: Edam, Gouda
- e) Red or yellow smear cheese: Tilsiter, Münster, Romadur, Limburger
- f) Surface fungus cheese: Brie, Camembert
- g) Fungus-based cheese: Roquefort, Gorgonzola, Stilton, double fungus cheese
- h) Salted cheese: brine cheese, Weisslacker
- i) Fresh cheese: nonripened cheese, quarg, cottage cheese, mozzarella
- j) Whey cheese

A general and internationally recognized classification is based on the raw material, type of consistency, interior and exterior (after indicating the type of milk, the type of cheese such as hard, semihard, semisoft and soft cheese is indicated), interior hole formation and surface characteristics (fungus, smear).

German cheese regulations differentiate between groups and standard cheese types (Overview 7./1). Other types can be classified according to their basic characteristics. Further, regulations distinguish between products made from cheese (e.g., processed cheese), cheese preparations (cheese with additions of other milk products) and cheese compositions (products with two or more cheese types).

Another classification is according to the chemical composition. To the consumer, the fat content is still of prime importance. Therefore cheese is classified according to its fat content, irrespective of its consistency, as shown in Table 7./1. If intermediate levels are used (e.g., 62% fat based on dry matter), it must be indicated. Further, fat content is always based on the dry matter content and not on the absolute percentage, abbreviated as FiDM.

Overview 7./1 Groups and types of cheese (a selection)

Group	Type	Fat level %	Minimum dry matter %
Hard cheese ≤56	Emmenthaler	45	62
	Chester (cheddar)	45, 50	60, 62
Semisoft cheese <54–63	Gouda	30,40,45,50	49,53,55,57
	Edamer	30,40,45,50	49,53,55,57
	Tilsiter	30,40,45,50,60	49,53,55,57,61
Semihard semisoft cheese >61–69	Steinbuscher	30,45,50	44,50,53
	Fungus cheese	45,50,60	48,50,53
	Weisslacker	40,45,50	45,47,49
Soft cheese > 67	Camembert	30,40,45,50,60	38,42,44,46,52
	Brie	45,50,60	44,46,52
	Romadur	20,30,40,45,50,60	35,38,42,44,46,52
	Limburger	20,30,40,45,50	35,38,42,44,46,
	Münster	45,50	44,46
Fresh cheese > 73	Quarg	<10,10	18-20,0,19-11.3
		20,30,	20-10,5,22-9.7
		40,45,	24-8,7,25-8.2
		50,60	27-8,0,30-6.8
	Layered cheese	≥10	≥20
	Cream fresh cheese	50	39
Acidified milk cheese	Double-cream	60	44
	Harzer	<10	
	Mainzer		
	Olmützer		

Table 7./1 Fat levels

Name	Fat content on dry matter basis in %
Double cream	≥60–85
Cream	≥50
Full fat	≥45
Fat	≥40
3/4 fat	≥30
Semifat	≥20
1/4 fat	≥10
Low fat	>10

To inform nutrition-conscious consumers and for comparative purposes, that actual absolute fat content can also be indicated. This can also be done by using factors for the calculation of the FiDM

Hard cheese	F = 0.7	Semisoft cheese	F = 0.6
Soft cheese	F = 0.5	Fresh cheese	F = 0.3

Further, dry matter (DM) in cheese is of importance. Hard cheese has a high dry matter content and a low moisture content; soft cheese has a high moisture content and a low dry matter content. Fat is included in the (total) dry matter content; therefore, a comparison of cheese types on the basis of dry matter is very difficult. For purposes of grouping cheese, the fat content f is not considered when evaluating dry matter content, and the term “nonfat cheese mass” ($100-f$) is used. The water content W in cheese is then expressed as the water content of the nonfat cheese mass W_{ff} and is calculated as follows:

$$W_{ff} = \frac{100 \times W}{100 - f} (\%)$$

The W_{ff} is therefore the water content of low-fat cheese type.

The ratios water content to casein content and water content to salt content basically determine the microbial ripening process and therefore the character and quality of cheese. Each type of cheese has to show a specific or normal water content of the nonfat cheese mass, at which protein has reached the ideal hydration level W_{ffN} and microorganisms will have the best growth conditions.

7.3. Technology of rennet cheese manufacturing

- Rennet cheese comprises hard cheese, semisoft cheese as well as soft cheese, which is manufactured by using proteolytic precipitation enzymes (rennet, microbial protease).

The production processes for the different types of cheese can vary greatly. Even the same type of cheese can be manufactured in different ways by each dairy. Here we want to show only the basic principles, from which the basic processes are derived. Additional process parameters and control factors are described which are relevant for the respective processing steps. Basic processes are given in Overview 7./2 in the form of a simplified flow sheet. The selection of the cheese milk and milk treatment in the dairy are not shown, but are described.

7.3.1. Milk selection for cheese

Cheese milk is the milk destined for the manufacture of cheese, traditionally also called “Kesselmilch” (kettle milk), derived from the cheese kettle, in which cheese was prepared ages ago. It is also called process milk.

- Cheese milk is a selected, standardized, more or less pretreated milk, which eventually has some additives; it is the basic raw material in the manufacture of cheese.

Cheese milk has to meet very high quality standards, so it must be selected very carefully. Its suitability is indicated by its disposition and its fermentation characteristics.

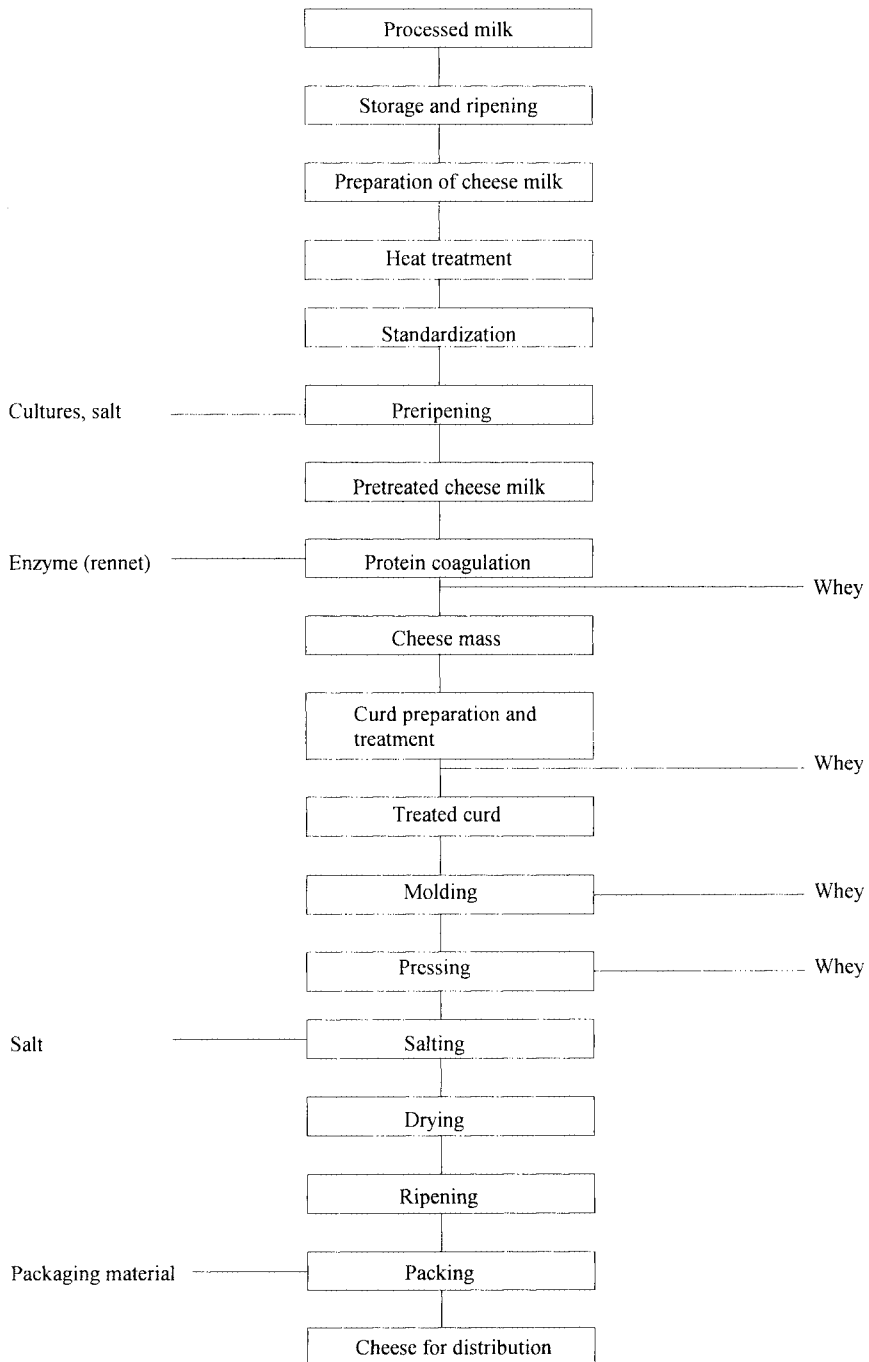
- Disposition is the sum of all the factors that influence the growth of microorganisms in milk, if procured aseptically from the udder.

If no contamination has occurred, then the key factors are animal stock, climate, soil conditions, feeding, maintenance of the animals, health, stage of lactation and chemical composition of the milk.

It is specifically the regional difference in feed, (e.g., due to climate, soil conditions, fertilization), which impart the special characteristics to milk, which is later converted into cheese. For example, milk from cows that roam in the mountains is especially suited for cheese types like Emmentaler. Therefore production of some cheese types remains localized. On the other hand, bad or spoiled feed can affect milk adversely.

- The fermentation suitability comprises all the factors affecting the growth of the microorganisms, which exist before the milk is treated.

Overview 7./2 Basic flowsheet for the manufacture of rennet cheese



In addition, factors such as growth of contaminating organisms and their metabolic products, milk production and treatment on the farm, and level of inhibitors, will influence fermentation.

- Suitability for cheese making means the suitability of milk for enzymatic and acid coagulation, curd treatment and the growth of all microorganisms which are important in cheese manufacture and ripening.

Cheese suitability comprises numerous process-influencing factors, which must be considered when selecting cheese milk. Indications are obtained from the organoleptic control of raw milk, (as done for quality assurance purposes for incoming milk) and some other parameters which are shown in Overview 7./3.

Overview 7./3 Evaluation criteria for the suitability as cheese milk

Characteristic	Requirement/effect
Inhibitors	Absence (antibiotics, residues of cleaning and disinfecting agents and other agents, which inhibit the growth of acidifying and ripening flora)
Acidification activity	Inoculation with 5% of cultures (as mentioned below) has to show the following: cheese culture after 6 h at 30 °C minimum 28 SH yogurt culture after 3 h at 42 °C minimum 30 SH butter culture after 7 h at 21 °C minimum 20 SH
SH value (titrable acidity)	> 6.0; > 7.4 for conversion see Section 2.3.2.5, Table 2./7
Temperature	Optimal storage at 6–8 °C, at < 6 °C protein modifications and reduced rennet activity, at > 8 °C too rapid growth of proteolytic psychrotrophic flora
Cell count	< 300,000/ml; (at > 500,000 increased level of leukocytes and impaired cheese suitability due to decrease of lactose, casein, calcium and phosphate content, increased level of κ -casein and reduced activity)
TPC	< 300,000/ml; increased TPC results in an increase of microbial metabolites such as heat-stable lipolytic and proteolytic enzymes, causing bad acidification and ripening performance of cheese milk
Level of technologically harmful bacteria	Free from proteolytic spore formers (clostridia), causing post-gas formation in hard and semisoft cheese
Rennet coagulation time	Milk with a significantly reduced rennet coagulation time is to be excluded
Coagulation test (fermentation test)	Simple check; the coagulation performance resulting from an acid or rennet treatment is evaluated in raw milk. This is a most suitable test but cannot be applied for pasteurized milk. Pasteurization reduces the content of gas-forming proteolytic microorganisms significantly
Organoleptics	Acceptable taste and smell, minimum 4 points in a test

Cheese suitability is also influenced by deep chilling and ensuing cold storage, mainly on the farm. This influence cannot be confirmed by normal control. Cooling (which is a basic requirement for stabilizing the microbiological quality of raw milk) to temperatures < 8–10 °C can lead to disturbances of the protein, ion and salt equilibrium in milk, which are widened by discharge of β -casein from the casein micelle, reduction of the protein-bound calcium and an increase of the negative charge of the casein micelle. As a consequence, we observe delayed acidification, prolonged coagulation times, impaired syneresis, and increased protein losses in whey.

- Raw milk, that is to be used for cheese-making should be chilled to not more than 8–10 °C and cold storage should be as short as possible (<24 h).

7.3.2. Milk treatment

Pretreatment of cheese milk consists of all activities and processes, that are required to achieve and stabilize a defined basic quality for the cheese-making process.

7.3.2.1. Preheating

Heating, which is the thermal treatment of cheese milk, can be differentiated into pasteurization (which is required by law and for hygienic reasons) and a second gentle heating (thermization).

Pasteurization. The objective is to improve the microbial quality of milk, i.e., totally inactivate pathogen germs and strongly reduce technologically harmful germs. This objective is achieved with the normal heat treatment processes; however, there are some disadvantages, e.g., disturbance of the calcium-casein complex due to precipitation of the calcium, which impairs the coagulability of milk, and partial coagulation of milk serum proteins, which increases the viscosity of the serum and thus makes separation of whey from the curd and the raw cheese more difficult.

Thermization. Thermization was originally conceived as a gentle heat treatment process for cheese milk but is used today mainly as a second process before or after pasteurization. This has the following advantages:

- a) Reestablishment of the equilibrium in milk which is disturbed by low temperatures, especially the protein distribution (reconstitution of the casein micelle)
- b) Increased microbial safety by inactivation of psychrotrophic bacteria, which are favored by low storage temperatures and are harmful for cheese, and of coliform bacteria due to recontamination of milk
- c) Possibility of addition of specific starter cultures for preacidification and protein hydration after the first thermal treatment
- d) Yield increase by 0.1–0.3 kg cheese per 100 l milk

If thermization of raw milk must be done before or after pasteurization, it must be demonstrated in specific trials.

- A favorable time/temperature combination for the thermization of cheese milk is 60–65 °C with 15–30 seconds holding time.

7.3.2.2. Storage

A basic requirement for a homogeneous composition or structure of the finished product is a constant raw material quality. This is the case especially when the production process has been fixed (e.g., automatic process control) or when continuous processes are used.

- Storage is used for standardization and also for preripening cheese milk.

The entire amount of milk (for processing on the next day) is stored in tanks at a temperature of 8–12 °C. Preripening can be initiated during storage. This means the addition of cheese culture to cheese milk (0.01% for hard cheese and up to 0.1% for soft cheese). For hard cheese and semisoft cheese, the storage temperature is set at 8–10 °C, for soft cheese the temperature range is 9–12 °C. Storage time is 14–24 h. Initiation of the preripening has the following objectives:

- a) Adaptation and minor growth of important lactic acid bacteria (the inherent increase of the SH value is not relevant)
- b) Improvement of the hydration state of casein
- c) Improvement of the cheese yield

7.3.2.3. Standardization

Standardization by storage means achieving a homogeneous composition of the original nonprocessed and nonmodified milk. Therefore a fat standardization has to take place. For large production capacities, using automated and partially automated processes, a standardization of the dry matter content (especially protein content), is recommended.

Fat content standardization. The fat content is adjusted by blending of whole and skim milk in tanks or by using standardization installations which also permit protein standardization (see 4.2.5.2).

The basic problem of fat standardization is that the final fat level is established in milk which has a completely different composition from the finished product (cheese) and no more adjustments can be made during the process. Further, during cheese making process not all the milkfat is transferred into cheese, as part of it remains in the whey, and this must be considered when adjusting the fat content.

Three factors are decisive for fat standardization:

Target fat content of the cheese to be manufactured
Protein content of the milk
Type of cheese

Fat content and type are given; the protein content must be determined. The protein content is determined by using rapid methods, such as measuring the protein titer; after preparing the sample, the acidic groups of the amino acids are neutralized with an alkaline solution. Using the protein titer (*PT*) and a correction factor *F* (based on trials) (see also Table 7./2) the fat content of the cheese milk can be calculated as follows:

$$f_{cm} = PT \cdot F$$

Table 7./2 Factors for fat calculation (according to Schulz and Kay¹)

	Fat level, fat in dry matter %						
	10	20	30	40	45	50	60
Hard cheese						0.93	1.09
Semisoft cheese		0.28	0.5	0.74	0.90	1.06	
Soft cheese		0.24	0.44	0.68	0.84	1.00	
Fresh cheese	0.17	0.33	0.55	0.79	0.96	1.12	1.6

¹ Schulz, M.; Kay, H.: Käseleitabellen, Hildesheim, Milchwirtschaftlicher Verlag Th.Mann KG, 1957.

Dry matter standardization. For maintaining the set parameters in the finished product and ensuring a smooth and continuous operation, dry matter standardization and protein standardization are important. A practical and economical solution is the application of *reverse osmosis* (see 4.2.5.2.2); however, some limitations are encountered when standardizing with milk powder or milk concentrates. Standardization of cheese milk by ultrafiltration can be done in three ways:

- Concentration of milk by a factor of not more than 2, followed by traditional production processes
- Concentration of milk by a factor of 3–6 followed by a modified process
- Concentration of milk to preset dry matter content of the finished product, for which other processes and installations are necessary

A suitable process is selected by considering the type of cheese to be manufactured, quality, yield and economic factors. Processes under a) is economically feasible only for certain soft and fresh cheese types. Processes under b) are the most economic variant and are suitable for nearly all types of cheese. Process variants under c) result in the highest yield, as all the fat and protein (including the whey proteins) are converted into cheese. However, a considerably different quality of the finished product can be expected. Therefore these processes are suited only for feta cheese and some fresh and soft cheese types.

Temperature conditions. After heating, cheese milk must be cooled immediately. The final temperature depends on whether milk is stored until the next day or consumed immediately. Storage is done at 8–12 °C.

Before using milk for cheese making, it must be tempered to the rennet processing temperature. For most types of cheese, this temperature is in the range of 28–34 °C, some types of cheese (e.g., butter cheese) require 41 °C.

Tempering cheese milk is done in such a way that the milk has a temperature of 1–1.5 °K below the target at the outlet of the plate heat exchanger in order to avoid a temperature excess. A final temperature adjustment can be made in the cheese maker.

7.3.2.4. Additional treatment

The objectives of other processes for the treatment of cheese milk are the elimination of spore forming bacilli or clostridia and to improve fat distribution.

Elimination of bacilli. During pasteurization of cheese milk, only the vegetative forms of microorganisms are inactivated, not the spores. Butter acid-forming bacilli (clostridia) and other types of organisms can cause defective fermentation in hard and firm semisoft cheese. It is advantageous to eliminate spore formers from the cheese milk. An effective and specifically designed process is the *bactofugation* (see 4.2.6).

Another possibility is a peroxidase-catalase treatment of cheese milk. In some countries the growth of butter-acid bacilli can be inhibited by adding hydrogen peroxide (about 0.2%). The hydrogen peroxide is then degraded by adding catalase.

Growth of butter-acid bacilli can also be inhibited by adding saltpeter. The addition of saltpeter to foods, however, is more and more restricted due possible health risks or is completely prohibited.

Homogenization. In order to keep fat losses as low as possible during the cheese making process, the fat content of cheese milk can be standardized with homogenized cream. For this purpose a cream fat content of about 40% and a homogenization pressure of about 180 bar at a temperature of about 60 °C are selected. At a lower fat content, a higher percentage of homogenized protein can prolong the coagulation time of milk and lead to lower firmness of the curd. Further, homogenization improves the salt uptake from the brine into cheese. If the homogenization step is eliminated, a whey decreasing becomes necessary in order to reduce fat losses.

7.3.2.5. Additives

After standardization and a second heat treatment (thermization), additives are incorporated into the cheese milk to reduce imbalances in the salt equilibrium and avoid later defective fermentation (gas formation), which can contribute to imparting a certain color to cheese. Starter cultures which are added in milk will be described in Section 7.3.3.

Improvement of the salt balance. In normal milk the salt equilibrium can be disturbed considerably by feeding, metabolic insufficiencies, too low milk temperature and too high pasteurization temperatures. Modifications of the casein-phosphate equilibrium considerably impair coagulation performance of milk.

By adding 10 g of soluble ionized calcium chloride per 100 l of cheese milk, the pH value is reduced, the coagulation times are shortened, and a firmer gel develops. Later additions do not result in a further improvement of the milk characteristics. The maximum amount permitted is 20 g per 100 l of milk. The crystalline CaCl_2 is dissolved in water at a ratio of 1:6 before being added to milk.

The phosphate content is decisive for the formation of the calcium paracaseinate-phosphate complex during rennet coagulation, for water binding in the rennet gel, and for the solubility of proteins and minerals. By adding 20 g of calcium phosphate per 100 l of milk, curd treatment times can be shortened and curd quality improved.

Rennet coagulation can also be improved by adding citrates. Ionized citrate links with the micelle-bound calcium, increasing the negative charge of the casein micelle and improving the gel structure.

Avoiding defective fermentation. “Early blowing” in cheese, i.e., gas formation by coliform bacteria, lactose-fermenting yeast and heterofermentative lactobacilli within 48 hours, is based on recontamination. This can be avoided by proper pasteurization, hygienic work procedures and acid control in the first phase of cheese ripening.

“Late blowing” in hard and semisoft cheese is caused by lactate-fermenting clostridia due to their strong growth and with gas formation, they can cause large, irregular holes and even large voids in cheese, thus significantly reduce the quality of the cheese, and can even cause spoilage. Clostridia form after a few weeks from the spores of clostridia, which have remained in milk. Taste defects are caused by their metabolic products.

Nitrate addition suppresses the growth of germinating spores of clostridia. On the other hand, nitrate can give rise to the formation of nitrosamine, which is considered a

health risk. In general, nitrate is added in the form of sodium nitrate (sodium saltpeter) to hard and semisoft cheese products.

- The nitrate addition must be kept as low as possible and should not exceed 15 g per 100 l of milk.

Normally the amount of additives is in the range of 10 g per 100 l; in many cases even 5 g per 100 l is sufficient.

Another bacteriostatic effect is observed when lysozyme preparations are added to cheese milk. Lysozyme, which is an enzyme existing in the liquids of the human body (saliva, tears) and also in plants and animals, causes lysis of cell membranes, mainly in germinating spores, but does not significantly influence acidifying bacteria. Addition of 100–250 mg of a lysozyme preparation to 100 l of cheese milk achieves the desired effect.

Colorant addition. In order to impart a matte yellow to yellow appearance to hard or semisoft cheese, natural organic food colorants such as carotene (provitamin A, β -carotene), riboflavin (lactoflavin, vitamin B) or carotenoids (annatto, bixin) are added. Quantities vary between different types of cheese and range from 5 to 10 ml per 100 l of milk.

7.3.3. Preripening process

- Preripening of cheese milk is the initiation of the acidification phase, which then controls all other ensuing phases.

The addition of a starter culture (depending on the group of cheese or type of cheese) initiates acid development and therefore pH reduction, which continues during curd acidification and acidification of the raw cheese and terminates during the salting step. At the same time, as a secondary effect, proteolysis of some proteins is caused by microbial activity of the microorganisms, which is more or less in evidence depending on the type of starter culture. Formation of flavor components is the one of the final steps in these complex biochemical reactions.

Even during storage, ripening can be initiated by the addition of small amounts of starter cultures (see 7.3.2.2). The main phase begins with the addition of starter culture after pasteurization and tempering and ends with the addition of coagulation enzymes into the cheese maker.

During preripening, contact between milk and ambient air in the processing room should be kept to a minimum (should even be excluded in order to avoid the risk of bacteriophages contamination). Bacteriophages exist in whey or in whey aerosols and cause lysis of lactic acid bacteria. Therefore whey should be removed as quickly as possible from the processing room.

Acidification. The pH value, whose reduction commences with the acidification step, is one of the decisive factors during the entire cheese making process and controls the following activities:

- a) Protein coagulation, both the enzymatic and acid precipitation of casein
- b) Curd treatment, i.e., syneresis and whey discharge
- c) Initiation of cheese ripening per se (main ripening) after the salting step
- d) Cheese ripening, (coinfluences the basic structure of the cheese type)

The degree of ripening of cheese milk depends on the coagulation enzyme used as well as the type of cheese and is in the pH range of 6.3–6.5. Sometimes the degree of the ripening milk is determined by the SH value, such as

Hard cheese	7.2
Semisoft cheese	7.2–7.6
Soft cheese	7.8–8.6

Acidification cultures, special cultures. Starter cultures for the acidification of cheese milk are of such a composition that they result in acid formation as well as more or less pronounced proteolysis and flavor development. The composition of the culture has a significant influence on the quality of the finished product.

By their specific metabolic performance, special cultures initiate some typical characteristics of cheese types, such as hole formation, mold and yeast growth. A possible composition of cheese cultures and their effects are shown in Overview 7./4. In a continuous or automatic process, acidification is accelerated by adding larger amounts of starter cultures, so that pH values of 6.3–5.9 (SH value 9–15) are reached at the beginning of the enzymatic coagulation. This increases enzymatic activity, and the coagulation process can be accelerated in such a way that the process becomes continuous.

Further, direct starter cultures or single type cultures are used (see 2.4.3) in order to control the process with smaller variations. Constant metabolic performance permits objective control of the production, which is advantageous for the control of larger capacities.

Maintenance and preparation of the cultures are important in the dairy plant, as some sensitive strains can easily degenerate and thus lose their effectiveness. Some rules must be followed for maintaining the acidification performance:

- a) Preparation of the intermediary culture in the rennet under sterile conditions and daily preparation of this culture for inoculation of the operational culture.
- b) Preparation of the operational culture in a “clean room” (separated from the production areas) in order to avoid phage contamination.
- c) Illumination of this room with UV light for inactivation of bacteriophages and generation of a slight overpressure by injecting sterile air into the room.
- d) Utilization of standardized milk with uniform quality which has a good acidification potential, high protein content and is free from inhibitors.
- e) Heating of the milk to 95 °C for 30 minutes.
- f) Compliance with optimal growth conditions; the incubation period must be chosen in such a way that the end of the logarithmic growth phase of the microorganisms is just reached or not exceeded to a large extent.
- g) Rejection of a degenerated culture and utilization of a fresh starter culture.

Figure 7./1 shows an installation for the preparation of a cheese culture. The mother culture, prepared and incubated in a glass flask, is injected with a sterile membrane pump into a tank (2) containing the heat-treated milk for preparation of the so-called intermediary culture. Incubation is then done in a water bath in the incubation installation (1), where the temperature is controlled automatically and the pH is recorded. By using sterile compressed air, the intermediary culture is transferred into the acidification tank (3), where the operational culture is prepared. From this tank, the starter culture is then dosed into the cheese maker.

For quality assurance purposes, the times and temperatures must be set in an activity plan.

Overview 7./4 Possible composition of cheese cultures (see also section 2.4.3, Overview 2./8)

Groups and types	Type of culture	Addition per 1000 l of cheese milk, requirements, effects
Hard cheese Emmenthaler and similar types	Thermophilic mixed culture with <i>Streptococcus salivarius</i> subsp. <i>thermophilus</i> , <i>Lactobacillus delbrueckii</i> subsp. <i>helveticus</i> as well as the mesophilic bacterium <i>Lactobacillus casei</i> in a ratio of 2:1:0.5:0.5 Propionic acid bacteria culture Thermophilic cultures	1.5–2.5 l; initiation of acidification in cheese milk by thermophilic streptococcus in the growth and incubation phase, where a population of 2–3·10 ⁷ per ml is achieved, with minor acidification. Strong growth of lactobacilli by curd post heating at > 45 °C. Creation of favorable pH conditions for latter ripening. 1–5 l; typical hole formation by propionic acid and CO ₂ formation during ripening. Growth stimulating for propionic acid bacteria during cheese ripening by creation of favorable pH conditions.
Chester	Mesophilic acidification cultures	5–20 l; Active acidification with minor formation of flavor and CO ₂ during the ripening.
Semisoft cheese Gouda, Edamer, Tilsiter and others	Mesophilic acidification cultures, partially with <i>Lactobacillus casei</i>	2–20 l; active lactic acid fermentation in cheese milk after incubation phase, intensive acid formation in raw cheese, good salt tolerance, strong flavor and CO ₂ formation at medium level of proteolytic activity during cheese ripening.
Fungus cheese	Mesophilic acidification cultures plus fungus cultures e.g., <i>Penicillium roqueforti</i>	Formation of a blue-green fungus network in the center of the cheese at high lipolytic and relatively low proteolytic activity. Too high proteolytic activity of the cheese results in a brown discoloration of the cheese and a bitter taste.
Semisolid semisoft cheese and soft cheese	Mesophilic acidification cultures	20–60 l; active acid formation in cheese milk, sufficient salt tolerance, no to very low flavor and CO formation and medium proteolytic activity.
Soft cheese with fungus (Camembert and others)	Acidification cultures and fungus cultures e.g. <i>Penicillium candidum</i> , <i>Penicillium camemberti</i>	100–200 ml; strains with good resistance to other fungi (e.g., <i>Mucor</i> types) with good growth rate of the conidia (at 20–22 °C 20% should have germinated within 10 h). Formation of an even closed mold surface on the cheese surface, creating the typical appearance and flavor.
Soft cheese with fungus (e.g. Romadur, Limburger) and cut cheese with slight greasy skin (Tilsiter)	Acidification culture with red cultures of <i>Brevibacterium linens</i> and coryneform bacteria mixed with acid-decomposing yeast	50–100 ml; formation of a yellow-orange to cream colored layer on the cheese surface, with formation of the typical flavor by proteolytic activity of bacteria. Even with completely ripened Camembert and Brie a small layer of red color is formed on the edges.

7.3.4. Protein coagulation

Traditional cheese technology requires that the protein, especially casein, must be separated from milk by coagulation. The colloidal casein particles with a stable and even distribution must be coagulated. This means that protein is converted from a sol state into a gel state (coagulate, gallert), specifically into a lyogel.

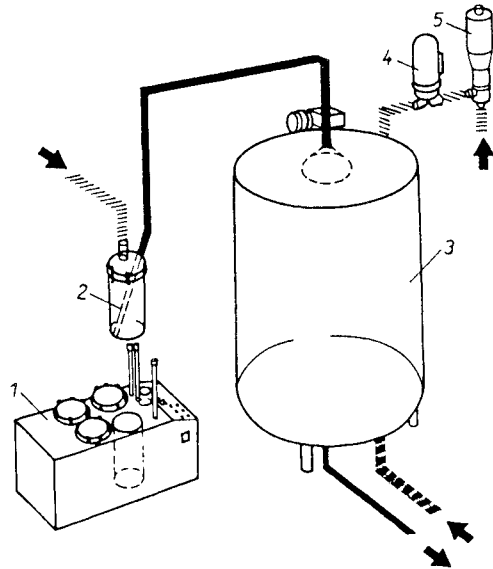
- Gels are semisolid gelled structures with some shape retention and elasticity. In the lyogel the casein particles are oriented in a three-dimensional honeycombed gel structure whose interstices are filled with water.

The structure of the gel that is created during milk coagulation has a significant influence on all later operations such as whey discharge, the ripening process and hole formation.

Figure 7.1 Installation for cheese culture preparation

(1) Incubator for preparation of intermediary cultures with tanks of 5–20 l content (2) Tank for intermediary culture (3) Tank for preparing manufacturing culture (4) Sterile air filter (5) Valve to control air flow or to control cleaning agents during cleaning

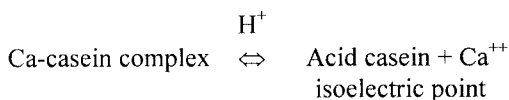
■ Milk
 ■ Mother culture
 ■ Sterile air



7.3.4.1. Basics

Basically casein can be coagulated in two ways, by reaction with acids (acid coagulation) and by enzymatic reaction (enzymatic coagulation), also called rennet coagulation. Pure acid coagulation is used for the manufacture of sour milk quarg, sour milk drinks and acid casein. Production of hard, semisoft and soft cheese is based on the enzymatic coagulation of milk with an additional acid reaction.

Acid coagulation. During acid coagulation the calcium phosphate complex of the milk protein is converted at the isoelectric point (see 2.3.1.3) into coagulated acid casein, and calcium ions are liberated and form calcium lactate (lactate is a salt of lactic acid).



This reaction is reversible; i.e., with addition of an alkaline or acidic solution beyond the isoelectric point, the acid casein can be resolubilized. This precipitation happens relatively slowly, as the individual protein fractions coagulate one after the other in a pH range of 4.6–4.9. Casein exists in the coagulated state only at the isoelectric point of pH 4.65. Acid casein is free of calcium and cannot be compared with the calcium-containing paracaseinate which develops during enzymatic coagulation.

Enzymatic coagulation. Casein consists of several fractions (see 2.2.1.3) which are bound to calcium by the casein micelle. The κ -casein has a unique position in this complex, and it can be found with large micelle on the surface, where it is insensitive and acts as a protec-

tive colloid. This protective action is based on the fact that parts of κ -casein, i.e., the glycomacropeptides or proteoses (non-protein-nitrogen NPN) project into the aqueous phase of the milk and form a hydration sphere because of their hydrophilic characteristics. The other part of κ -casein is calcium sensitive and is bound to it like other fractions. As the hydration sphere has an equal negative charge, individual casein micelles repel each other, i.e., remain solubilized in colloidal form, and precipitation is avoided.

Casein precipitation takes place in two steps:

Enzymatic phase (primary phase)

Coagulation phase (secondary phase)

In the enzymatic phase, the κ -casein protective colloids fractions of glycomacropeptides and the hydrating sphere of the micelle disappear, and the protection against a joining disintegrates.

During the coagulation phase, at an optimal temperature and optimal pH, salt bridges form between the Ca-sensitive micelles because of the existence of calcium ions, reacting rapidly (linking) and causing precipitation. (Figure 7./2). The lyogel which forms has a net-like, honeycomb-like, or three-dimensional structure, which can be compared to that of a porous sponge.

The water-insoluble calcium caseinate complex formed from the colloidal dissolved calcium-caseinate complex is called either coagulum, rennet gel, rennet gallert and is the real cheese material.

Milk serum proteins are not affected by the enzymatic reaction. They remain water soluble and migrate as whey proteins into the aqueous phase. Coagulation enzymes have both a precipitation function and a weak proteolytic effect in the ensuing processes.

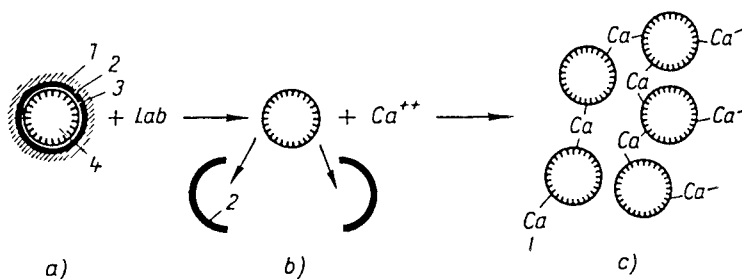


Figure 7./2 Schematic of casein coagulation according to the protective sphere theory (according to Payens)

a) Intact casein micelle b) Casein particle without the effect of the protective colloid c) Rennet gel (calcium paracaseinate)

(1) Hydration sphere (2) Glycomacropeptide hydrophilic part of κ -casein (3) Calcium-sensitive part of κ -casein (4) Other calcium-sensitive protein fractions, especially α_s -casein

7.3.4.2. Factors in enzymatic coagulation

The coagulation of milk is influenced mainly by the following factors:

- Type and concentration of coagulation enzyme
- Properties and concentration of proteins (substrate properties)
- Coagulation temperature
- pH value

Coagulation enzymes. Enzymes used in milk curdling (coagulation) are acidic proteases. A traditional coagulation enzyme is chymosin (sometimes also called rennet), which is extracted from the stomachs of calves and is called calf rennet or simply rennet. A high demand for coagulation enzymes and insufficient supply of calf stomachs led to rennet substitutes or coagulants, which are preparations made of microbial proteases. These include rennilase, made from a fungus culture (*Mucor miehei*). The chymosin gene has been isolated with genetic methods from calf stomach cells and has been used in microorganisms such as *E. coli* or *Kluyveromyces lactis*. Proteases manufactured in such a way are nearly as effective as real calf rennet.

Protein-degrading enzymes such as pepsin are extracted from the stomachs of pigs, cattle, chicken and other animals (vegetative proteases). Individual enzymes are also made into blends and used as such. Due to their weaker coagulation effect (compared to calf rennet or microbial enzymes) and greater nonspecific proteolysis, pepsin preparations are used in the manufacture of fresh cheese.

Nonspecific proteolysis is an attack on certain peptide bonds of casein outside normal coagulation, sometimes leading to the formation of nondesirable bitter peptides, taste defects in cheese.

Additives. Influencing factors are pH value, concentration and coagulation activity of the enzyme preparation. The rennet strength is defined as follows:

- Rennet strength indicates the number of parts of cheese milk with an SH of about 7 and a temperature of 35 °C that can be curdled by one part of rennet in 40 minutes.

Calf rennet is offered in powdered form in a strength of 1:100,000 or as a liquid rennet extract in a strength of 1:10,000 or 115,000. Rennilase is offered in a strength of 1:46,000. Rennet strength can be calculated as follows :

$$L = \frac{V_M \cdot 100 \cdot 2400s}{V_L \cdot T}$$

L = rennet strength

V_M = milk quantity in ml

V_L = rennet solution used in ml

T = coagulation time in seconds

s = time unit

For reproducible tests, 100 ml of milk which has been reconstituted from milk powder is chosen. When using liquid rennet, 2 ml is topped off with distilled water to 100 ml, and then 1 ml is pipetted. When using rennet powder, 0.5 g is dissolved in 100 ml of distilled water, and then 1 ml is pipetted. Figure 7.3 shows the relative coagulation time for some enzyme preparations as a function of pH value. Calf rennet with a strength of 1:100,000 is used in quantities of 1.5–2.5 g per 100 l of cheese milk; rennilase is used at a level of 4.0–4.5 ml.

Substrate characteristics. A key factor is the concentration in cheese milk of casein, which is the substrate for an enzymatic reaction. An additional factor is the salt equilibrium in milk, especially the calcium content and calcium solubility. These parameters must be kept constant for the design of an optimal process during cheese production.

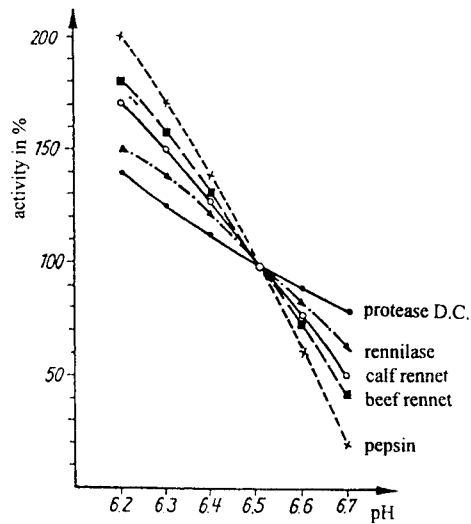


Figure 7./3 Relative coagulation activities of different enzymes as a function of pH (pH 6.5 = 100% activity)

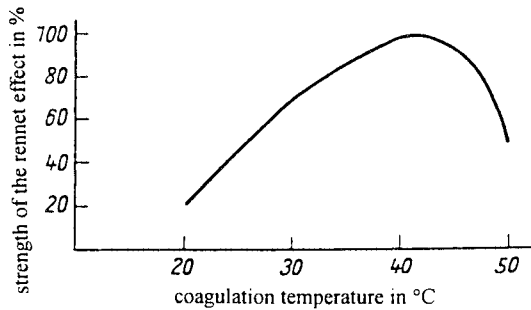


Figure 7./4 Effect of temperature and rennet coagulation

Substrate standardization is one of the most difficult things to realize. In Section 7.3.2.3., possibilities are described. The kinetics of a coagulation process are influenced decisively by the protein content. According to Reuter and Hisserich¹ the time for the first coagulation phase (from the point of addition until coagulation) is reduced in the form of an exponential curve for a milk whose protein content has been raised by ultrafiltration from 3.5 to 20%. By varying the protein content, coagulation time can be controlled in connection with the amount of enzymes used .

Coagulation temperature. A maximum effect of calf rennet is achieved at 41 °C (Figure 7./4). However, this temperature is used for only a few types of cheese, e.g., butter cheese. All other rennet cheese types (except fresh cheese) are made with coagulation temperatures of 28–34 °C, which also offers an optimum between the enzymatic, acid and heat effect.

Coagulation time (from the time of adding the enzyme until the beginning of coagulation) and curdling time (from the time of adding the enzyme until the beginning of curd-

Reuter, H.; Hisserich, D. u.a.: Formalkinetik der Labgewinnung von durch Ultrafiltration konzentrierter Milch. *Milchwissenschaft* 36 (1981), pp 13 to 18.

ling) depend on the coagulation temperature. Data shown in Table 7./3 can be used for curdling temperatures and times. Coagulation temperature further influences water binding and therefore the stability of the gel, its shrinkage as well as its acidification.

Coagulation temperature has an impact mainly in the secondary phase of the coagulation process. The enzymatic primary phase can also take place at temperatures < 10 °C. Knowing these relationships, to accelerate coagulation in a continuous process, a “cold” coagulation can be done during storage. When the coagulation temperature is set, the primary phase has already taken place; coagulation starts immediately and curdling time is drastically reduced. But there is a question of whether the modifications in product quality due to these process modifications can be accepted.

Table 7./3 Curdling temperatures and times

Type of cheese	Temperature in °C	Time in min
Soft cheese	28–32	120–150 (winter) 30– 90 (summer)
Semisoft cheese	28–32	30– 40
Hard cheese	32–35	30

pH value. As described in Section 7.3.3. at the end of preripening milk should have a cheese specific pH value or a corresponding SH value before adding enzymes. This influences the enzymatic activity (see Figure 7./3); enzyme dosing is adjusted accordingly and the coagulation time is fixed.

Coagulation time is selected mostly as a function of technology and economy, and the enzyme quantity is dosed accordingly. The enzyme-acid ratio is not considered in many cases. For optimal coagulation, a favorable pH range is 6.2–6.5. Table 7./4 shows coagulation times as a function of pH value and the type of enzyme at constant enzyme quantities. A pH range of 6.1 to 6.3 is favorable; the added quantity can be kept low and can counteract a nonspecific proteolysis. Curdling time depends on coagulation time.

Table 7./4 Coagulation times in min with a constant enzyme dosing as a function of the pH (pH 6.5 = 15 min)

pH	Pork pepsin	Rennet extract	Rennilase
6.7	75	30	22.5
6.6	30	22.5	17.5
6.5	15	15	15
6.4	11	12.5	12.5
6.3	9	10	11
6.2	7.5	9	10

- Curdling time is the period from the point of adding the enzyme to the commencement of curd preparation (cutting of the gel) and is a factor of 2.5 of the coagulation time.

Technique for adding enzymes. Enzyme is added to cheese milk at the end of all treatment steps, i.e., at the end of the preripening period. Normally the following method is used:

- a) Dissolution of the powdered enzyme preparation in lukewarm water or dilution of the liquid extract in 5–10 times the amount of water
- b) Blending of milk and addition of the diluted enzyme solution with constant stirring
- c) Rapid stop of milk circulation

Thorough blending of milk in the cheese maker with stirring devices (not with cutting devices) yields an even distribution of a significantly increased lactic acid bacteria population (during the preripening stage). The better the bacterial distribution in small colonies in the milk, the better is their metabolism and therefore the acid development. During curdling, the cheese maker, tanks or trolleys should not be subjected to mechanical shock, otherwise the structure formation is disturbed, resulting in a low curd quality as well as significant protein losses.

7.3.5. Curd and curd treatment

At the end of the curdling time, milk has coagulated into a compact gel mass which must be broken down for further treatment. The more or less large gel-like particles are called cheese curd or curd.

7.3.5.1. Basics

During enzymatic coagulation all the water in milk is bound in the gel as whey. The major part of it is found in the pores or interstices of the gel as interstitial liquid, which can be discharged easily after the interstices open.

Another part is bound in the capillaries between the casein particles as capillary water, whose percentage is greater if the network of the gel is finer. Removing the capillary water is more difficult. Most of it remains in the cheese and influences acidification, ripening and the final water content during the process. A small part of the water is chemically bound hydrate water.

Shrinking. Gel contracts and discharges water during shrinking (contracting), which is also called syneresis. Here the following forces act:

- a) Contraction forces of the paracaseinate network (gel)
- b) Shrinking pressure of whey
- c) Flow resistance of gel to whey

During syneresis, contraction forces act first and shrink the interstices (which are filled with whey); as a result the liquid is subjected to a higher pressure (shrinking pressure) and is discharged. The gel structure exerts a flow resistance, which is controlled by the firmness of the gel and the distance of the whey from the outside. Syneresis is further influenced by the acid content. The lower the pH value, the greater is the contraction of the curd and therefore the whey discharge.

Skin formation. In a rennet gel a skin is formed as casein particles accumulate in the outer layers of the curd. We can distinguish between adhesion skin, surface skin and contraction skin.

Adhesion skin is formed on the milk/vessel interface and is evidenced by more or less pronounced adhesion to the wall of the vessel. Surface skin is formed at the milk/air interface, whereby accumulation of the casein particles is caused by the surface tension.

Contraction skin which is formed around the curd particles and is influenced especially by the water discharge. In rapid dewatering of the boundary layers of curd, skin formation is more pronounced than in even dewatering from the curd.

Acidification. Acidification bacteria are fixed in the gel by coagulation, which enhances once again the requirement for good blending of milk before adding enzymes. During curd formation, a second active acidification phase takes place, which is characterized by increasing lactic acid fermentation. The population of lactic acid bacteria grows from 50–100 million per gram to 500 million–1 billion per gram after coagulation during molding of the cheese during molding of the cheese.

Table 7./5 Guidelines for the composition of some raw cheeses after salting

Cheese type	Mass g	Moisture % (+/- 1%)	pH value (+/- 0.1)	Salt content % (basis ripened cheese)
Emmenthaler	84800	55.0	5.20–5.30	1.9
Chester	30000	56.0	5.20–5.40	1.6
Gouda	6600	59.9	5.15–5.30	2.2
Edam	3030	59.5	5.10–5.30	2.2
Tilsiter	3150	62.0	5.10–5.30	2.5
Fungus cheese	3210	66.0	4.60–4.80	3.0
Steinbuscher	750	68.0	5.00–5.30	2.8
Butter cheese	1050	67.0	4.80–5.00	2.0
Limburg	280	72.0	4.80–5.00	3.0
Romadur	140	73.0	4.80–5.00	3.0
Camembert	145	77.5	4.70–4.90	3.0
Brie	2300	77.5	4.75–4.95	3.0

7.3.5.2. Curd treatment technology

Curd must be treated according to the type of cheese manufactured; i.e., gel particles must be treated more or less intensively.

- Curd treatment means controlling water content, pH value, temperature, pressure and latter the salt content so that after salting, a raw cheese with very defined characteristics and composition develops which is typical of the specific type of cheese.
- Raw cheese is a freshly molded, sometimes pressed and salted before the main ripening step.

In order to achieve the targeted values for fat in dry matter, mass and moisture, these parameters must be controlled in raw cheese. Therefore curd treatment must be designed accordingly. Composition of some cheese types is shown in Table 7./5. Data in parentheses show the maximum tolerances. Water content and pH value can be influenced during curd treatment by the following:

- a) Cutting of the gel
- b) Influencing the porosity of the boundary layers of curd particles
- c) Temperature profile
- d) Washing of the curd

Cutting of the gel. The closed homogeneous gel of coagulated milk is cut into smaller or larger pieces with the objective of having a free surface for the discharge of the interstitial water and to enhance syneresis. Curd is therefore cut either manually (with a saber, knife or harp; see Figure 7./5) or by machines with installed devices (see 7.3.10.2) into strips of 2–3 cm width and then into cubes. For soft cheese there is no more curd treatment as there is only a small amount of whey to be removed. For hard and semisoft cheese, curd must be cut multiple times.

- Cutting must begin slowly and carefully, in order not to destroy the soft gel, to avoid an increased protein transfer into the whey (cheese dust¹).

It is important to recognize the correct time for cutting. At the end of the curdling time, the gel should show a typical structure with some firmness and elasticity. These physical properties determine the time of cutting but cannot be measured objectively due to their complexity. In most cases the time for cutting is determined empirically according to visual impressions, which requires some experience. The following characteristics must be considered:

- On breaking the curd over a round object, the broken surface should show a broken chinaware appearance.
- Removal of the gel from the inner wall of the vessel (when the adhesion skin has formed sufficiently, the gel is detached from the wall surface).
- Determination of the SH value of the gel.
For semisoft cheese the SH value has increased by 1–1.5 SH vs. beginning.
For soft cheese the SH value has increased by 1.5–2 SH vs. beginning (for this a bottle with noncurdled but acidified milk can be used as a reference. The SH value is determined by titration).
- Determination of the SH value for whey, which should be lower by 2–4 SH (due to the absence of the curdled and acidic protein) vs. the beginning.

The size of the curd particles at the end of the curd treatment depends on the type of cheese. Examples are

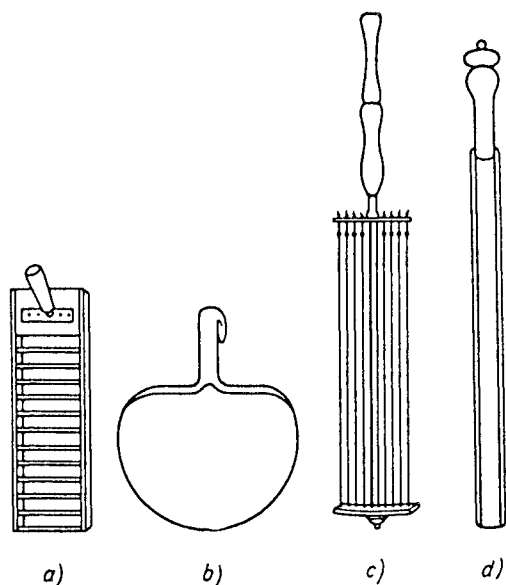
Type of cheese	Curd particle size
Emmenthaler	rice grain
Tilsiter/Edamer	pea
Camembert	walnut

Ladling. For some hard and semisoft cheese types the gel surface is ladled some time before cutting. For this purpose, a surface layer a few centimeters thick is ladled and inverted. This serves to destroy the surface, reheat the cooled surface and redistribute the creamed fat.

Influencing the porosity of the boundary layers of curd particles. This serves to achieve an even discharge of whey from curd grains and to avoid the formation of too thick a contraction skin.

During uneven dewatering of curd particles, whey is discharged more rapidly from the interior, leading to narrowing of the paracaseinate network in the boundary layers and the development of a skinny surface. This increases flow resistance, and the whey discharge from the interior is disturbed and even stops.

¹ Cheese dust is small casein particles, formed by the destruction of the soft gel and migrating into whey.

**Figure 7.5****Tools for the curd treatment**

a) Curd knife b) Ladle c) Harp d) Saber

With too high a whey content the core of curd particles is overacidified, which later leads to structural defects like “short” and “chalky.” Due to a higher moisture content during ripening and storage, a whey discharge in cheese (“postdischarge”) can be observed.

The objective of curd treatment is to achieve a uniform homogeneous core with a corresponding porosity of the boundary layers, which can be influenced by the following controlling parameters:

- a) Coagulation temperature (too high → skinny grain)
- b) Enzyme quantity (too high → skinny grain)
- c) Size of curd particles (too large particles where the contracting pressure is insufficient to surmount the flow resistance → skinny grain)
- d) Time of additional cutting (an additional cutting has to take place at the beginning of the narrowing of the curd particle boundary layers, too late cutting → skinny grain)
- e) Stirring of the curd (too intensive, rapid stirring → too strong contraction → skinny grain)

Temperature profile. Acidification and contraction during the curd treatment can be controlled by temperature. The greatest influence is exerted by temperature in the cheese maker and ambient air temperature.

Temperature in the cheese maker. For some hard and semisoft cheese types (types with a low final moisture content) curd is postheated (or “burnt”) when only small amounts of water can be removed by cutting and stirring. This temperature increase enhances syneresis, and we also observe a discharge of hydrate water from curd.

The cheese maker is heated up with either steam or hot water (circulation in the shell of the double-walled vessel) and temperature is increased while stirring constantly, thus

raising the temperature of the entire curd mass. Temperatures for postheating are raised to 55 °C for hard cheese and 45 °C for semisoft cheese.

At these temperatures contaminating harmful germs are inhibited in their growth or are inactivated. Thermophilic acid formers such as *Streptococcus salivarius* subsp. *thermophilus*, *Lactobacillus delbrueckii* subsp. *helveticus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* are enhanced in their growth.

Room temperature. At too low temperatures in the processing room, a delay in coagulation as well as syneresis is observed. Further, the surface of the preformed cheese compacts, which then leads to insufficient whey exchange, early gas formation and defective fermentation. Ambient air temperature in the processing room should be > 20 °C with a low air circulation and no drafts of air.

Washing of the curd. Once part of the whey has been removed from the cheese maker, the curd is washed for some types of cheese (e.g., Gouda, Edam). Warm water is added to the curd/whey mixture (both having the same temperature), with the water quantity corresponding to 15–25% of the used milk quantity.

Washing enhances whey discharge, and acid is removed from curd, which contributes in setting the pH optimum for raw cheese. At the same time it imparts a milder taste to the cheese.

7.3.6. Formation, turning and pressing

Separation of the curd/whey blend is initiated by whey discharge from the cheese maker. At the time when the cheese is given its typical shape, raw cheese has to solidify and must be set to the targeted values.

According to the type of cheese, the whey discharge is more or less enhanced. We observe the same phenomena for whey discharge from raw cheese as observed during whey discharge from curd (syneresis, skin formation, porosity).

Thermal time. The period from molding the cheese until salting in the brine bath is called the “thermal time.”

- Thermal time is time of “warm” temperatures, which are needed for optimal acidification of the cheese.

This is a phase of an intensive lactic acid fermentation which later influences considerably the consistency of the cheese mass, hole formation and the formation of fungi and the smear layer. Further, rapidly reaching the optimum pH can displace coliform bacteria and thus avoid “early” gas formation. Tests on Gouda cheese showed that the level of coliform bacteria was ten times higher if a pH < 5.4 was reached after 5–6 hours instead of 3–4 hours. If the thermal time is reduced for economic reasons i.e., the cheese is transferred too early into the brine bath, quality defects can be expected.

Molding. The finished curd is filled into molds which are typical for the type of cheese. The softer curd the gentler this activity must be. The molds must be tempered before filling; i.e., the temperature of both mold and curd should be adjusted. Molds are mostly plastic, rarely metallic or wooden; they are equipped with cloth in order to improve their filtering effect.

Molds can have a square, rectangular or circular shape and impart their dimensions (width, length, height or diameter) to the cheese mass. The height is 2–3 times the height of the finished product, which is reduced by whey discharge, thus reducing the mass.

The size of the cheese depends on the type and is a function of its dry matter content. Soft cheeses types (low dry matter content) have small dimensions, release whey easily, are kept well together in their interior and can ripen well. Semisoft cheese, especially hard cheese, must be larger, otherwise it would dry out during the significantly longer ripening periods. This is valid, however, only for ripening in laminate (foil) or with paraffin coatings. Some semisoft cheese types (e.g., “baby” Gouda) can have smaller dimensions, as they are protected by the coating against drying out. When ladling manually, it is important to fill the molds evenly, especially for cheese that is sold on a piece basis.

Smaller cheese types are filled into molds which are assembled into multiples on sheets or plates and are filled by using a funnel. In a mechanized operation curd is filled in the same way into these multiple molds and standardized to size (portioned) at the end. For large cheese types, molds are filled with curd individually or are shaped in molding devices and then portioned with cutting devices.

Molding influences the hole formation. If the curd is “grainy” or “stable” during ladling and the curd mass remains relatively porous after the discharge of the whey, curd holes develop (with some hard and semisoft cheese types). If the curd is soft, these holes collapse, and whey can accumulate in some places, creating so-called nests of whey.

Turning. After molding, cheese is turned over several times to enhance whey discharge, achieve a uniform shape and initiate formation of a skin. Turning is done individually for large cheese types, smaller cheese types are turned on racks. Initially the cheese is turned 5–8 times every 15–30 minutes, later every 1–2.5 hours according to the type of cheese.

Pressing. Pressing accelerates both the whey discharge and deacidification and compacts the cheese mass. Pressing is done both by the force of the mass of the cheese cake and by external forces.

Auto-pressing (with a significantly reduced effect) is done mostly for soft cheeses and for semisoft cheese with so-called slit holes (e.g. Steinbuscher, Tilsiter). Pressure depends upon the column height of the form (or form battery) and increases from top to bottom with multiple turning, the direction of the pressing is changed and uniform whey discharge and shaping of the cheese is achieved.

For pressing in pressing devices, the ratio between force and cheese mass as well as an additional parameter (the surface of the cheese, on which the force is exerted) is of importance. During pressing each additional force of 1 kg per kg cheese remains unchanged if a corresponding change in the surface of the cheese is realized. In case only the height of the cheese mass is modified, the cheese is subjected to stronger forces. Pressure forces are not standardized and are subject to the following parameters:

- a) Pressure per kg cheese
- b) Pressure for the piston of the press and
- c) Pressure onto the surface of the cheese

In most cases the pressure exerted by the piston of the press is indicated based on the cheese surface. This pressure can be determined easily and read from a pressure gauge; and it can be well controlled. We see the following values:

middle-sized cheeses (Gouda, Edam)	2–5 bar for 3–4 hours
large-sized cheese (Emmenthal)	3–10 bar for 12–14 hours

Based on cheese mass, the values are 15–20 bar/kg for small to middle-sized cheese and 30–40 bars/kg for larger cheese types for identical times. The actual pressure on the surface of the cheese is significantly less.

The pressing operation must be controlled in such a way that it starts at a low pressure, which is then gradually increased. Too high an initial pressure dewateres only the outer layers of the cheese, so that the pores of the cheese cake close prematurely, similar to a skinny grain. Whey discharge is very slow even at pressures > 10 bar.

In some mechanized installations there are two pressing operations, a curd prepressing—where curd grains are joined into a large block and portioned into the desired shapes and dimensions—and the main pressing operation. Other processes are designed in such a way that cheese is pressed in an individual mold, and the distinction becomes blurred.

7.3.7. Salting

Each type of cheese has a specific salt content, which decreases with decreasing dry matter content.

The main purpose of salting is to influence the taste of the cheese. It also regulates the acid content and has a preservative effect against the germination of gas-forming organisms (which favor the ripening flora), favors hydration (water binding) of the cheese dough and promotes the formation of the skin. Finally, it influences the solidification of the cheese, which increases with increasing salt concentration.

Salt content of cheese. The salt content is specific for the type of cheese (see Table 7./6). When indicating the salt content in cheese we have to distinguish between

- a) Salt concentration in cheese, $c_{NaCl, K}$, in g NaCl per 100 g cheese or in %
- b) Salt content in the aqueous phase of cheese, $c_{NaCl, W}$, in g NaCl per 100 g water or in %

Once $c_{NaCl, K}$ or $c_{NaCl, W}$ is analyzed, the missing concentration can be calculated as follows (with W = water content in cheese¹):

$$c_{NaCl, C} = \frac{W}{\frac{100\%}{c_{NaCl, W}} - 1} \text{ in } \%$$

$$c_{NaCl, W} = \frac{c_{NaCl, C} \cdot 100\%}{W + c_{NaCl, C}} \text{ in } \%$$

The salt coefficient K_{NaCl} is the quotient of the salt concentration and water content. It yields good comparative data between the different types of cheese and is also a process guideline. The following coefficients are applied: for fungi cheese 6.0%; for Emmenthal, Chester, Tilsiter, Muenster, Steinbuscher, Limburg and Romadur 4%; for Edam, butter cheese, Camembert and Brie 3.2%; for Gouda 3.0% and for Neufchatel 2.4%. The salt coefficient is derived from the equation

$$K_{NaCl} = \frac{100\% \cdot c_{NaCl, C}}{W}$$

¹ See also Spreer, E.: Berechnungen in der Milchindustrie, 2. Aufl. Fachbuchverlag, Leipzig, 1989.

Types of salting. This describes how salt migrates into the cheese. We distinguish between the following types of salting, which can also be utilized in a combined form:

- a) Salt addition to the cheese milk
- b) Curd salting
- c) Dry salting
- d) Salting in a laminate bag
- e) Injection of salt
- f) Salting in brine bath

Salting into cheese milk. The main purpose of adding the salt to cheese milk is to improve its cheese making properties, as the development of mainly coliform bacteria is inhibited. Salting therefore has importance, especially for lower milk qualities. It is a disadvantage, however, that a considerable part of the dissolved salt is washed out with the whey and is an additional load for the wastewater system. Additions are in the range of 4 kg of salt per 1000 l cheese milk.

Curd salting. In some types of cheese (cheddar, Chester and others) salt is added in the form of a solution to the curd/whey mix or by spraying onto the curd, once 10–30% of the whey has been removed.

Added salt amounts to 2 kg per 1000 l of cheese milk. The purpose of the salt addition is to promote even salt penetration into cheese and to accelerate whey discharge.

Dry salting. Here cheese is evenly covered with salt (either by dry coating or sprinkling), so that it can adhere to the entire surface. Salt consumption is about 7 kg salt per 100 kg cheese.

Apart from high salt consumption, this process requires, especially for soft cheeses, high rennet activity, when salting is done manually. For larger production capacities, salting machines are used; salt is applied mechanically and evenly, and excess salt is re-dried before being reused.

Dry salting has the advantage that whey discharge is strongly promoted, salt uptake is very even, and contamination with technologically harmful germs, as they can appear in brine baths, is excluded.

Salting in a laminate bag. Here each individual cheese is placed in a bag, which contains a defined amount of a salt solution of a known concentration. Cheese can also be dry salted before being placed into the bag. For better salt distribution, cheese can be covered with an absorbable material (cloth or paper). Cheese remains in this bag together with the salt solution until ripeness has been achieved (subject to the type of cheese) or is removed after 4–6 weeks. After this period, the surface must be dried off, so that the ripening can continue without the bag. Due to low liquid losses, the cheese yield can be improved by 2.5%.

Injection of salt. In this process a salt solution (23% NaCl content at 20 °C) is injected into a freshly molded raw cheese by using injection needles. In an automatic process, the cheese weight is determined beforehand and the amount of brine is calculated. This process permits a uniform salt content in cheese.

Salting in a brine bath. This is the most common and economical type of salting, and a salt consumption of 3–4 kg per 100 kg cheese can be foreseen.

For this purpose, salt is dissolved in water and cheese is immersed in this brine. Installation for brining are made with ceramic or stainless steel; bulk tanks are made with bricks or concrete, which are coated with plastic. Cheese loaves are immersed individually or in racks (Figure 7./6)

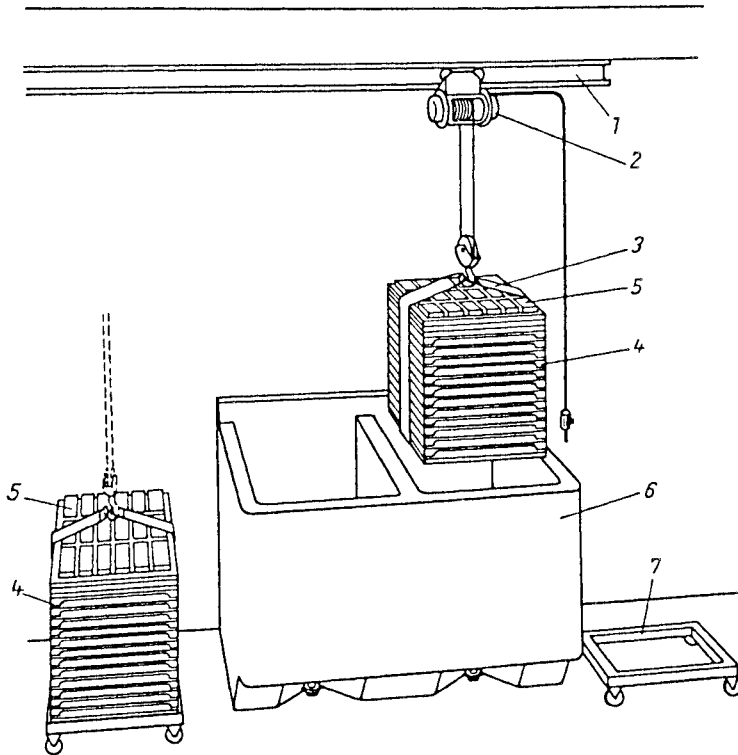


Figure 7./6 Brine bath device for soft cheese

(1) Overhead rail (2) Lifting device (3) Lifting belt (4) Racks (15 packed racks, 1 empty rack, 1 covering rack) (5) Bricks for extra load (6) Brine bath (7) Trolley

Processes in the brine bath. When cheese is surrounded by brine, an exchange with the less concentrated whey takes place through the semipermeable layers of the cheese mass. The driving force is the osmotic pressure (see 4.2.5.2.3) and the liquid pressure of the brine. In Figure 7./7 this process is shown schematically, with values related to a firm semisoft cheese immediately after the end of a brine bath.

This exchange continues until equal concentrations in the solutions are achieved. In reality, complete exchange is avoided by removing the cheese from the brine bath. Salt distribution and penetration into the interior of the cheese continue; its intensity depends on the water content and brine concentration.

Together with whey, milk ingredients—mainly protein—migrate into the brine bath, and settle on the bottom of the tank in the form of sludge. This means losses of cheese mass, which must be considered in yield calculations (called brine bath losses). They are in the range of 4% for semisoft cheese and 10% for soft cheese.

Brine has to meet certain requirements, which must be controlled and maintained. Key parameters for the activities in brine are salt concentration, temperature, salt content in the cheese and time for salting.

Salt concentration. Subject to the type of cheese, the following brine concentrations are used:

Hard and semisoft cheese 19–22% salt content
Soft cheese 16–18% salt content

Density can be determined with a brine spindle (araeometer), and the concentration can then be calculated by using a value of 2.16 g/cm^3 for salt. Brine density is 1.116–1.161 g/ml. In some cases spindles with Baumé readings are used, as they have a more detailed scale (see Table 9./2). The optimal Baumé readings are between 15 and 20.

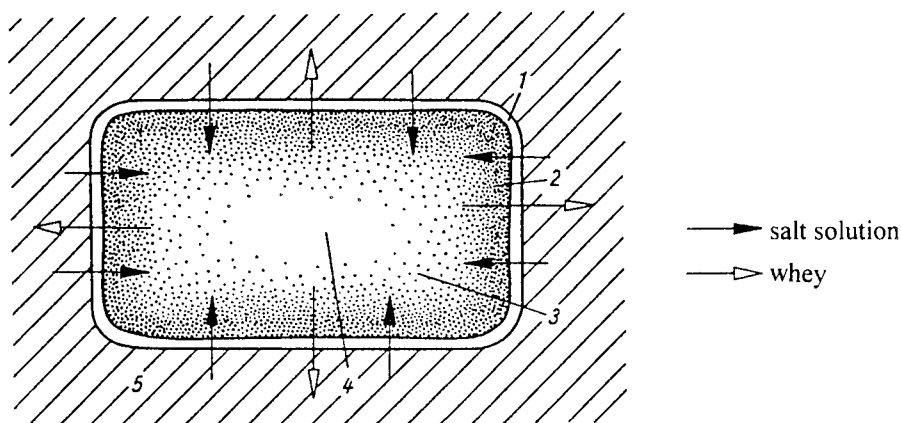


Figure 7./7 Exchange of whey and brine during the salting of cheese (NaCl content in parentheses)

(1) Outer boundary salt ring (6.0–6.2%) (2) Salt region (3.8–4.2%) (3) Regions of exchange (1.2–2.6%) (4) Core (0–0.25%) (5) Brine

Temperatures. High temperatures result in a high salt uptake, low temperatures a lower salt uptake. The velocity of salt uptake can be controlled by temperature, therefore the water exchange over time. Brine temperature for hard and semisoft cheese is 12–17 °C, and for soft cheese 18–22 °C, which corresponds to the temperature for mold growth.

Acid content. During salting, the pH in cheese reaches its lowest value since the beginning of the acidification, which should be 5.0–5.2 for hard cheese and 4.8–4.7 for soft cheese (see Table 7./5). Setting of these values is a basic requirement for the desired smooth consistency during ripening.

At an increased pH, especially for hard and semisoft cheese, a tough dough can be expected; at a too low pH a “short” or “chalky” structure can be expected. Soft cheese requires a slightly lower pH, as it can deacidify more rapidly during the ripening because of its smaller size.

- The pH value of the brine should be adapted to that of raw cheese.

Sometimes acid is determined in the brine bath by the pH method as well as the less precise SH method (titrable acidity), and the following SH values are used for some selected types of cheese:

Emmenthal	12	Gouda	15
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Tilsiter	18	Steinbuscher	23
Camembert	27		

A freshly prepared brine bath must be adjusted to the proper pH before being used, which is done best by adding lactic acid. Sometimes whey is used, which needs to be pasteurized before utilization in order to avoid contamination with harmful organisms.

Salting period. This depends upon the following factors:

- Desired salt content in cheese
- Brine concentration, expressed in kg NaCl per kg of water or in %
- Specific surface of the cheese as a quotient of cheese surface and volume
- Water content W of the cheese
- Diffusion velocity of the salt into cheese

Salting periods of some types of cheese are shown in Table 7./6. Complete migration of salt takes 4 days for soft cheese, 4 weeks for Tilsiter and 4–5 months for Emmenthaler.

Table 7./6 Residence times and permitted salt content in selected types of cheese

Type of cheese	Residence time in brine	Salt content in %
Weisslacker	6 days	6
Emmenthaler	4–5 days	2
Gouda	20–40 hours	2
Tilsiter	40–60 hours	2
Steinbuscher	8–12 hours	2.5
Camembert	20–100 min	2.5

Brine maintenance. After a longer period of operation, the deposited sludge (consisting of milk ingredients, mainly protein and crystalline salt) is separated, pasteurized (in order to avoid possible contamination) and filtered; sometimes the brine bath is completely renewed.

The level of microorganisms can be kept low during its operational life by adding growth retardants such as chlorine compounds, hydrogen peroxide or silver compounds. The discharged sludge must be removed as special waste.

After regeneration, brine is brought back to the desired concentration by adding salt. When adjusting the concentration by density, it must be considered that milk ingredients also play a role in the density before regeneration, and they have been eliminated now. For example an 8-week old brine which has a spindle reading of 18 % salt, in reality contains only 16%; the difference comes from the milk ingredients.

7.3.8. Surface drying

After salting, the cheese surface must be dried well in an air current. For this purpose cheese is transferred to the drip and drying room, where a drying process takes place under the following climatic conditions:

Temperature	17–19 °C
Relative moisture	75–85 %

Intensive drying of the surface is important, especially when cheese is packed into laminate or is surrounded by wax (see 7.8.3). The surface of Camembert and Brie also must be dried well, otherwise undesirable mold will grow, and the growth of the fungi is delayed or even suppressed. Further, with an insufficient drying, strong yeast growth on the surface can take place.

7.3.9. Cheese ripening

- Cheese ripening is a biochemical process which takes place under physical, microbial and enzymatic conditions. A nearly tasteless raw cheese is converted into a smooth, tasty finished product having many characteristic properties.

Requirements are given by using mechanical-physical processing techniques, beginning with milk treatment until the stage of molded raw cheese, addition of starter cultures and coagulation enzymes and finishing in a mainly biochemically controlled ripening process. The following factors contribute in the enzymatic control:

- a) Coagulation enzymes
- b) Naturally occurring milk enzymes
- c) Metabolic activity of the microorganisms and their microbial enzymes

Processes such as proteolysis, lipolysis, glycolysis, gas and flavor development are initiated, and the required ripening flora and contamination flora develop. These processes terminate in textural and organoleptic modifications of cheese during and at the end of the ripening process.

7.3.9.1. Processes during ripening

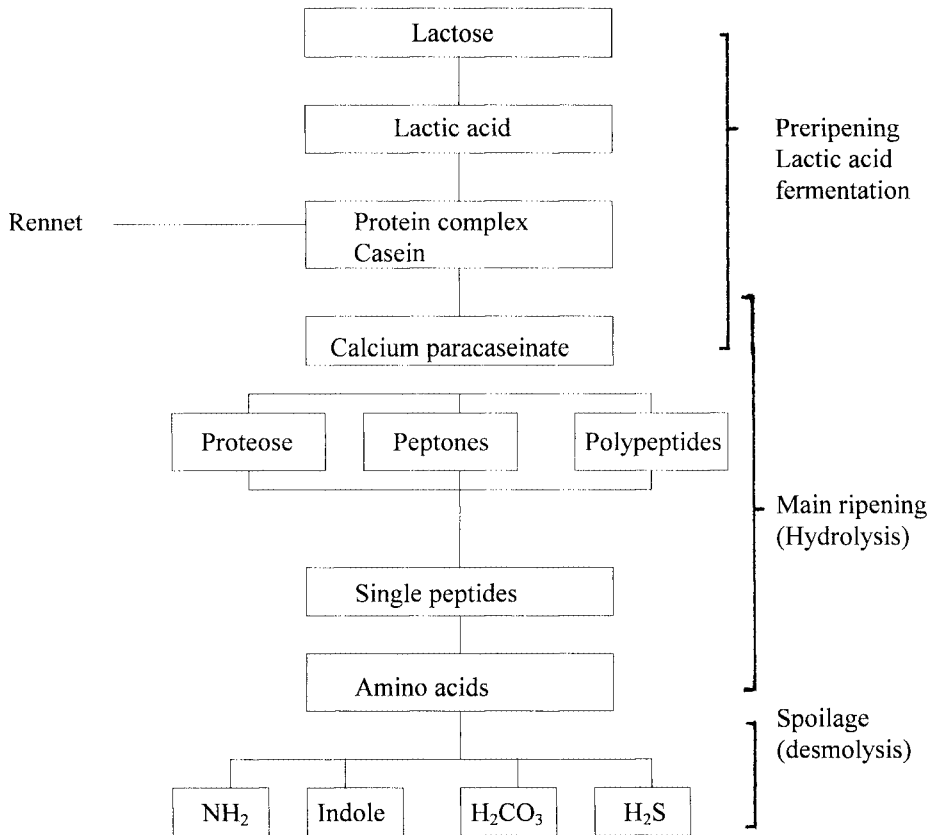
Adding starter culture to cheese milk begins the phases of priripening and characteristic acidification, covering the stages of curd treatment and raw cheese treatment including salting. The next process is the main ripening or cheese ripening. Fresh cheese is also called nonripened cheese, although microbial place do take place in this product. Product changes which occur during ripening of cheese can happen simultaneously or sequentially. Therefore a clear distinction is not always possible, but these processes can be seen as organoleptic, chemical and microbiological changes.

Organoleptic changes. During cheese ripening these changes must be constantly controlled by the dairyman and are key factors in the organoleptic evaluation of the finished product. The basic visible changes are:

- a) Development of a more or less solid skin, which can be, depending on the type of cheese, dry, coated with a smear layer or coated with a fungus (exterior)
- b) Development of a homogeneous, soft to firm dough of white to yellow color (interior)
- c) Development of holes (eyes), slits or cracks

Chemical reactions. Proteolysis of casein is the most important chemical reaction during cheese ripening. Cheese mass reacts by a hydrolytic denaturation (denaturation by adding water) through various stages, which can take place simultaneously, proceeding until the stage of basic molecules, i.e., amino acids. A further denaturation would be spoilage. The most important stages of the proteolytic denaturation are shown in Overview 7./5.

Overview 7.5 Schematics of the chemical reactions during cheese ripening



Additionally, a fat denaturation (lipolysis) takes place. Fat contains lipophilic flavor compounds, which develop or are released by microbial or enzymatic action through oxidation, decarboxylation and eventually reduction of decarboxyl compounds.

Conversion of lactose (glycolysis) is also initiated by adding a starter culture, and reaches its peak in the milk during the preripening stage. Here lactic acid, acetic acid and CO₂ are produced.

Microbiological reactions. Metabolic activity of microorganisms and enzymatic reactions are closely linked with chemical reactions, showing the biochemical character of the cheese ripening process. A basic requirement for an optimal ripening process and therefore good cheese quality is the development of a specific ripening flora. This is evidenced by the surface flora and by hole formation in the interior of the cheese.

Surface flora. For many types of cheese this means some fungi and mostly yeast. Their metabolism has the following effects:

- Fermentation of lactose, limiting acid formation
- Assimilation of lactic acid (acid decomposition)
- Growth stimulation of certain bacteria by the development of essential vitamins (nicotinic acid, pantothenic acid, lactoflavin)
- Flavor development by the formation of volatile acids and carboxylic compounds

On the surface of cheese are mostly yeast such as *Candida* and *Torulopsis*, as well as *Kluyveromyces* and *Debaryomyces*. As molds we find *Geotrichum candidum* (white milk fungus) and *Penicillium caseicolum*.

Colonization with yeast on the surface of cheese begins after the whey separation and reaches its peak a few days after salting (10^7 – 10^8 yeast cells per cm^2). It is the yeast which creates favorable conditions for the future dominant surface flora, which can be different from cheese type to cheese type.

Due to the microbial population on the surface of the “wet” cheeses (Romadur, Limburger, Tilsiter), a slightly wet to dry coating develops. This is caused by the protein denaturation of coryneform bacteria, especially strains of *Brevibacterium linens*, which develop orange, yellow or white pigments.

For soft cheese with a surface fungus (Camembert, Brie and others) ripening is initiated in the same way as for the “wet” cheese types. Besides a growth of mainly *Penicillium candidum* (white fungus), covering the entire surface of the cheese, it is of importance to know that other fungi, e.g., *Mucor*, are suppressed at the same time. In trials it was shown that a strong yeast population, e.g., *Kluyveromyces marxians* can restrict *Mucor* development to a large extent.

- The higher the yeast population on the surface of cheese, the lower the survival potential of harmful fungi.

A good yeast population can be achieved by adding yeast to cheese milk (about 10 cells/ml). The growth of fungi, however, can be delayed or suppressed if the yeast population (e.g., *Candida* types or *Geotrichum candidum*) is too large, which again can favor other fungi types.

Hole formation. Hole formation, which is closely linked to dough consistency, is a major quality criterion of the finished product. Hole or slit formation is controlled by the cheese production process and by microbiological reactions. Formation of curd holes and whey nests has already been described in Section 7.3.6 (forming); therefore only the aspect of hole formation by microorganisms will be described here.

Process of hole formation. Through the metabolic activity of microorganisms, i.e., proteolytic and glycolytic reactions (especially during the splitting of lactate), propionic acid, acetic acid and gas products such as carbon dioxide (and during defective fermentation hydrogen) are formed.

These gases diffuse through the cheese dough and develop the typical holes, especially in locations where there are the initial points for voids (holes). In a smooth dough with a uniform consistency and an even distribution of microorganisms, more or less pronounced hole formation takes place throughout the entire interior, especially for hard and semisoft cheese. If, however, a brittle, tough cheese mass is available, then the gases produced cannot diffuse evenly and slowly, so that in locations with a stronger gas formation too large, irregular holes are formed, and cracks develop in the cheese. In general we observe:

Smooth, plastic dough uniform → sphere-like holes

Brittle (chalky) or tough dough → irregular hole formation, cracks

The different gases lead to different types of hole formation. CO_2 is formed slowly and evenly, and due to its good water solubility it leads to uniform hole formation. Hy-

drogen, develops explosively and irregularly due to harmful germs such as coliforms or butter acid bacilli. Because of this and its low water solubility, hydrogen develops many small holes (where it is formed) and the dough is torn apart.

Participating microorganisms (see Overview 7./4). As long as lactose is still available, lactic acid bacteria participate. They form holes only by developing small amounts of CO₂; other by-products such as acetic acid, alcohol or diacetyl in small quantities are also produced.

The typical hole formation of some hard cheese types (e.g., Emmenthaler) comes from propionic acid bacteria (e.g., *Propionibacterium freudenreichii*). These bacteria ferment lactic acid but mainly calcium lactate into propionic acid, acetate and CO₂.

Microbiological reactions during hole formation as well as chemical reactions during cheese ripening depend mainly on water activity (see 2.3.1.1). For a desired ripening profile, rennet cheeses need water activities of $a_w = 0.91\text{--}0.96$.

7.3.9.2. Ripening profile and conditions

Ripening profile. Due to the different acid levels in cheeses and their different dimensions, the ripening process proceeds very differently.

In all types of cheese, acid decomposition occurs first. It starts in the brine with yeast and/or fungi on the surface of cheese and continues during proteolytic ripening. Proteolysis continues as the cheese mass is deacidified. This is very evident in high-moisture and high-acid cheese types (soft cheese), which are more dewatered in the outer zones than in the interior.

Proteolytic ripening therefore starts from the outer zones and progresses into the interior as a function of the acid decomposition. Therefore soft cheese ripens visibly from the outside to the inside. Hard and semisoft cheese, having a lower acid level and a uniform dewatering during curing (ripening), ripen more uniformly throughout the entire cheese mass.

- Soft cheese ripens from the outside to the inside; hard and semisoft cheese ripens uniformly throughout the entire cheese mass.

Ripening conditions. After salting or drying, cheese is transferred into ripening rooms or cellars, where favorable climatic conditions must prevail. These conditions are characterized by temperature and relative humidity. Conditions are shown in Table 7./7.

Table 7./7 Ripening conditions and times

Cheese type	Temperature in °C	Rel. humidity %	Ripening period in weeks (w) or days (d)
Hard cheese (Emmenthaler)	14–15	80–85	2 w
	20–22	80–85	8–10 w
	14–17	85–90	1–2 w
	10–13	85–90	4–8 w
Semisoft cheese	13–16	85–90	5–10 w
Soft cheese	16–19	90–95	10–30 d

Emmenthaler and other cheese types with similar hole formation show a special ripening profile. Here ripening begins with a preripening at 12–14 °C, whereby the ripening flora adapts to the environment and can develop. Main ripening follows at 20–22 °C, and

is characterized by vigorous lactate and protein denaturation as well as a strong CO₂ formation; it is the key phase in the hole formation. During the postfermentation holes are still expanding, but gas formation is significantly reduced. Gas formation does not entirely stop even during the storage period (until consumption) at temperatures of 10–13 °C.

Soft cheese has a completely different ripening profile. Optimum ripening conditions are, for example, Camembert: 1–2 days of drying at 16–18 °C, 75–80% rel. humidity and 0.2 m/s air velocity followed by ripening at 13–14 °C, 90–95% rel. humidity and 0.01 m/s air velocity.

Cheese does not always remain in the dairy until consumption ripeness is reached. This may be achieved by storage at the wholesale and retail level. The cheese quality depends to a large extent on the storage conditions. Some types of cheese are packed into laminate or wax before distribution (see 7.8.3). Therefore we distinguish between natural ripening and laminate ripening. During ripening cheese must be turned over several times, subject to the type of cheese. The purposes are:

- a) Maintain a good shape
- b) Achieve uniform drying by turning over the wet bottom side
- c) Develop an even mold or smear growth

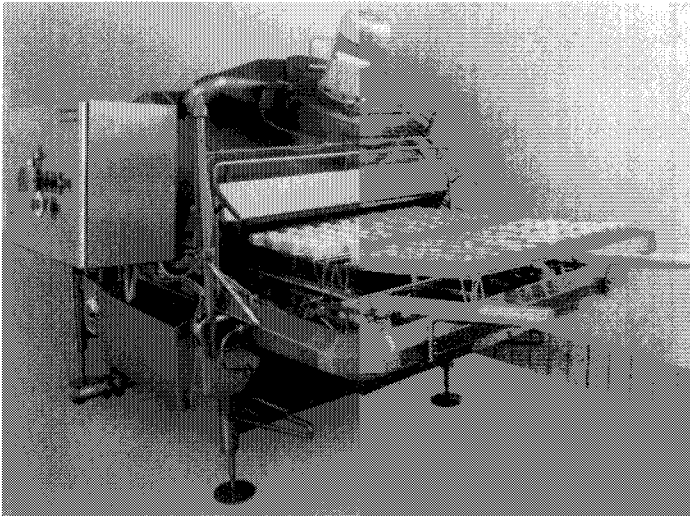


Figure 7./8 Machine for spraying and smearing of cheese for tray handling

Further, cheese with a smear surface coating is brushed or sprayed with a weak brine, sometimes containing a red culture and colorant. Machines, such as the one shown in Figure 7./8, can be used. The purposes of brushing are:

- a) Avoid mold growth
- b) Promote the growth of red smear bacteria (*Brevibacterium linens*)
- c) Achieve a uniform wet surface

During ripening cheese is placed on trays which are combined into stacks or racks.

7.3.10. Workplace and technical equipment

7.3.10.1. Rooms

In a rennet cheese plant, special working areas are required which are normally kept separate. They can be separated into main and auxiliary rooms. The main working areas consist of:

- Processing room, where cheese milk is prepared, curd is treated, and forming, pressing and turning are done.
- Salting room, where cheese is salted. Sometimes a drying room is attached
- Ripening rooms. These are air-conditioned rooms or caves with constant climatic conditions for the ripening of cheese, often until consumption ripeness is achieved.
- Packing room, including storage rooms and cold storage. Packing is done here as well as storage of the cheese until distribution.

Auxiliary rooms include areas for washing and drying of utensils (forms, trays, mats, sheets), whey storage, storage for auxiliary material and packing material, laboratory, rooms for CIP and rooms for the air conditioning installation.

Apart from normal hygienic requirements, especially for the main areas, which must be easy to clean, good illumination, roomy, clean, tiled walls and acid-resistant floors, other aspects must be considered, such as:

- Ceilings must be coated at least once a year with chalk or must be kept free from microorganisms and insects by other means. They should be well insulated, in order to avoid condensation water.
- Good air ventilation with temperature control, preferably with air conditioning (see Section 14.4) is required.
- Drainage for whey and wastewater must be kept separate.

The layout of the rooms must permit a continuous flow of operations (see Figure 7./9)

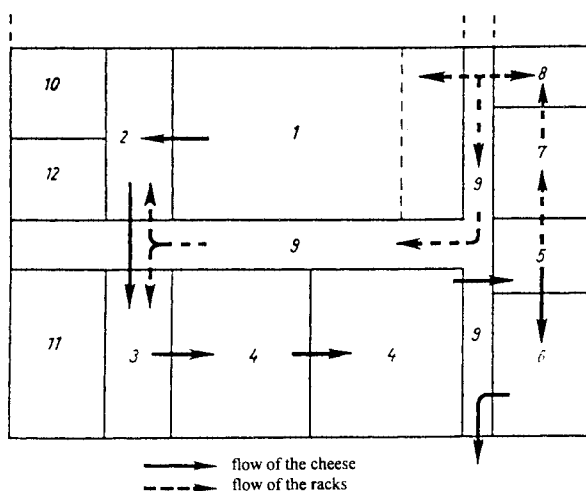


Figure 7./9 Layout of a soft cheese plant

(1) Processing room (2) Salting room (curing) (3) Cheese drying room (4) Ripening rooms (5) Packing room (6) Cold storage (7) Washing room (8) Drying room (9) Hallway (10) Whey storage (11) Laboratory (12) Storage area for auxiliary material

7.3.10.2. Technical equipment

Technical equipment can range from a simple “classic” installation as used in cheese plants for a long time to completely mechanized installations with modern processes including a nearly automatic process. The trend toward the fairly lately introduced completely mechanized cheese plants is based on modified product qualities, and some cheeses have lost their typical characteristics. Exact measurement and computerized operation of process parameters are the basis for an automated operation.

Traditional and partially mechanized processes. Technical equipment has been reduced to basics with a clear orientation toward the types of cheese to be manufactured. Nearly all operations are done manually. Standardization and preripening of cheese milk, protein coagulation and curd treatment are done in cheese troughs or vessels with a double wall for water and steam connection and large-diameter discharge valves for the discharge of curd. Soft cheese plants also have tilting troughs, which permit easy distribution of curd into the molds (Figure 7./10). A layout with curd preparation and manual turnover is shown in Figure 7./11. For larger capacities and higher productivity, cheese making installations having basically an elongated oval or cylindrical shape are being used.

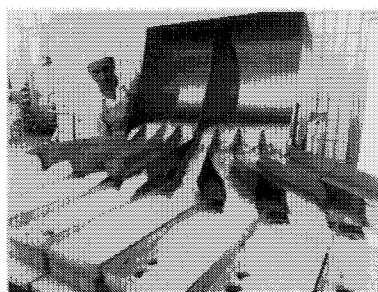


Figure 7./10
Mobile and tilting cheese trough with distribution device during discharge

Cheese maker with mobile stirrer (Figure 7./12). In this cheese maker, also called a “Gouda vat” or “colander,” curd is treated with a stirring and cutting device which moves across the trough by means of an overhead rail. This device rotates around its vertical axis and covers the entire contents of the trough. The net volume of these troughs is 3000–10,000 l, with a net volume utilization of 90%.

Cheese maker with a cylindrical shape. A cutaway of such a cheese maker is shown in Figure 7./14, and a description is given in Overview 7./6. In this cheese maker, cheese milk is prepared, curd is treated and filling into forms takes place. Different types can be distinguished mainly by these characteristics:

- a) Location of the drive for the installations (top or bottom)
- b) Form and type of devices
- c) Control (manual or automatic)
- d) Device for curd discharge

For example curd can be discharged under vacuum, thus permitting very gentle treatment, or it can be discharged with curd pumps or by gravity flow. Net volume of the cheese makers is 4000–20,000 l.

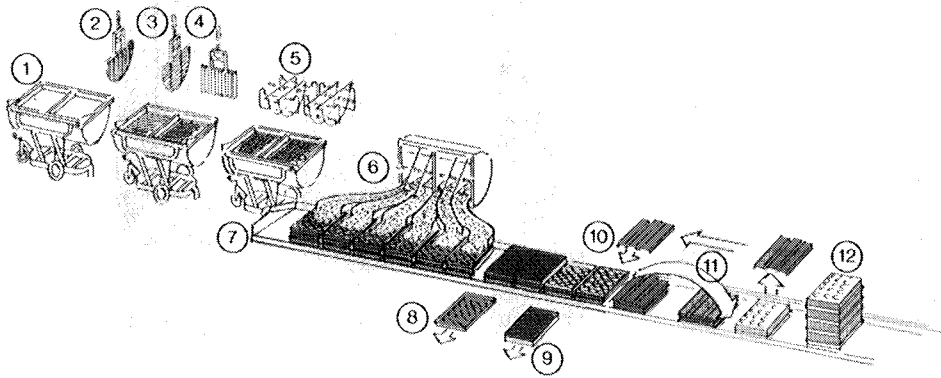


Figure 7./11 Flow diagram for preparation of cheese curd, capacity max. 5000 l/day

(1) Coagulation of milk in curd tank (2) Vertical cutting (3) Horizontal cutting (4) Lateral cutting (5) Curd cutting inserts (6) Portioning with curd cutting device (7) Cheese table (8) Removal of mold funnels (9) Removal of inserts (10) Placement of turning sheets (11) Rotation of molds with two turning sheets (12) Stacking of molds and drainage

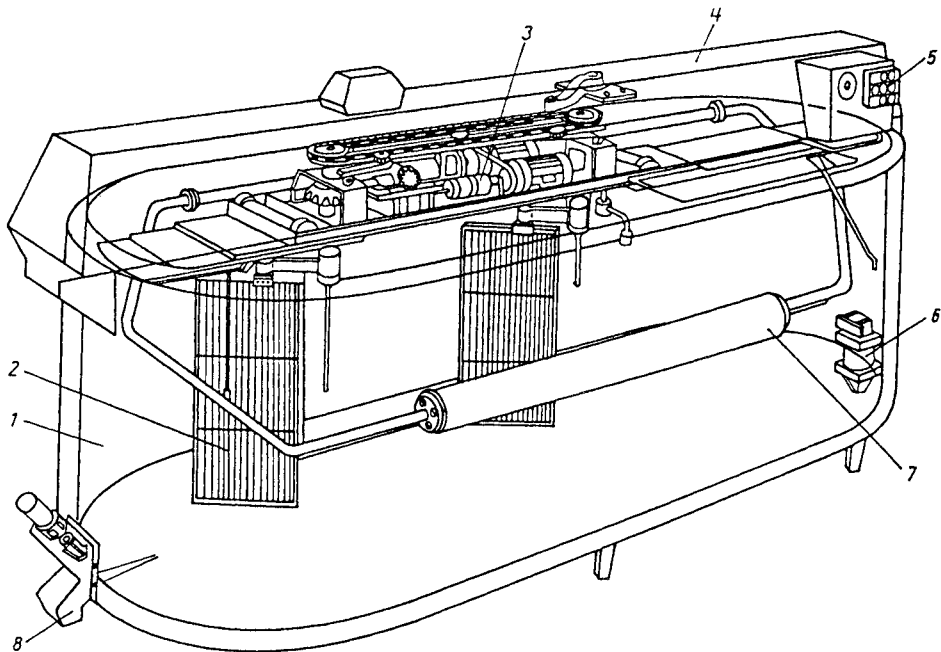


Figure 7./12 Cheese maker, type Tebel-Matic

(1) Double-walled vessel for the product, heating with water (2) Wire-cutting stirring device (3) Drive, gearbox and rail (4) Drive housing (5) Control panel (6) Water or steam valve (7) Whey discharge with sieve (8) Curd discharge valve

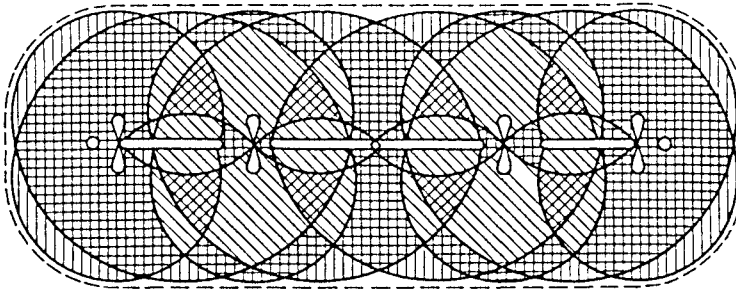


Figure 7./13 Orbitals of the stirring and cutting device in the cheese maker

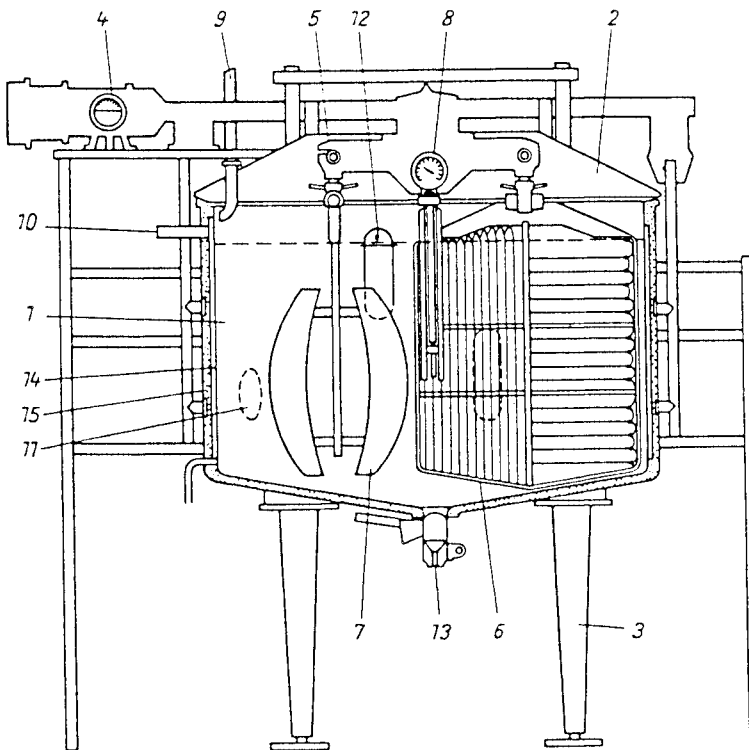


Figure 7./14 Cheese maker type 486

(1) Double-walled tank (2) Lid (3) Feet (4) Varidrive (5) Planetary gearbox (6) Wire cutter (7) Paddles (8) Thermometer (9) Inlet pipe (10) Steam or water inlet (11) Whey discharge (12) Side-glasses (13) Curd discharge valve (14) Tempering shell (15) Insulation

Presses are simple lever or spindle presses, with which pressure is set manually, pneumatically controlled vertical column presses (Figure 7./15) or horizontal presses. For larger process capacities with a higher degree of process automation, pressing is differentiated between prepressing and pressing. First, curd is transferred into a prepressing chamber, where the residual free whey is discharged and curd grains are formed into large compact blocks. The press is shaped like a trough, is equipped with a perforated bottom and can serve as a transport device. After filling the trough, perforated sheets are added

Overview 7./6 Cutaway of a cheese maker (see Figure 7./14)

Part	Purpose	Remarks
Cheese maker (1)	Reception of the product	Inner and outer wall made from stainless steel. Two hollow spaces: inner for tempering, outer for insulation
Lid (2)	Covering the vessel	Two parts, can be opened
Feet (3)	Support of the vessel	Height adjustable
Drive motor (4)	Drive of the planetary gear	Varidrive 1–16 RPM, right and left rotation
Planetary gearbox (5)	Drive for the curd treatment devices	Joint rotation around the center of the vessel plus rotation around itself
Wire cutter (6)	Cutting and disintegration of the gel (curd formation)	A wire is installed across the frame (horizontally and vertically)
Paddles (7)	Movement of curd	Wirecutter and paddles can be removed. can be replaced by stirrers if required
Thermometer (8)	Temperature indication	Protected and removable
Inlet pipe (9)	Inlet for milk	The bend permits foam-free filling
Steam/water inlet (10)	Tempering of the product	Water and steam can be mixed as a function of temperature required
Whey discharge (11)	Discharge of part of the whey	A sieve is installed before the valve, which retains curd particles
Sideglasses (12)	Level control	
Curd discharge valve (13)	Discharge of curd	Connection of curd discharge and curd transfer devices for a gentle and uniform mold filling

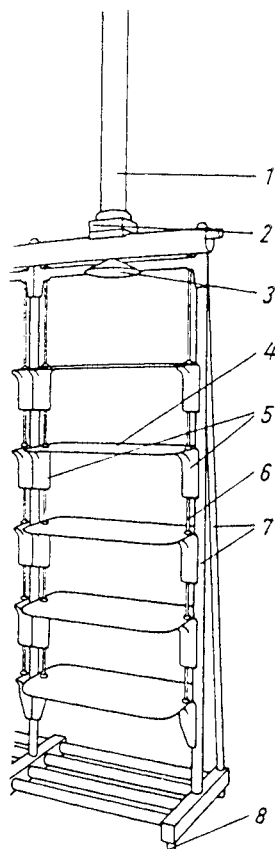


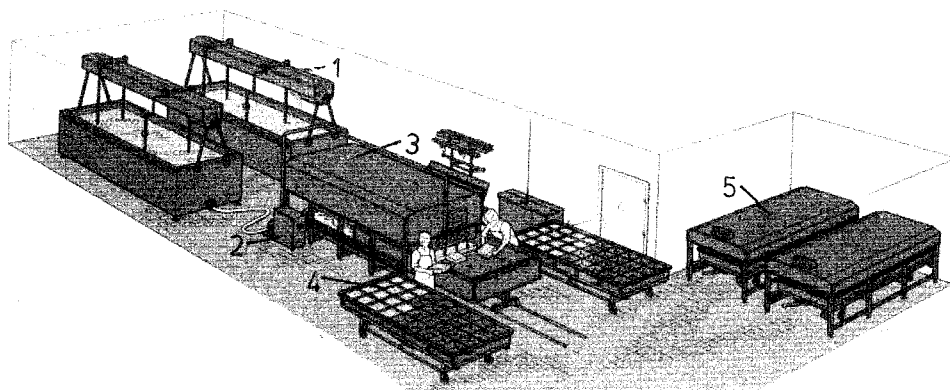
Figure 7./15 Section of a pneumatic vertical column press

(1) Pressing piston (2) Operating lever (3) Pressing disk (4) Pressing sheet (5) Guidance for pressing sheet (6) Support for pressing plates (7) Frame (8) Adjustable feet



Figure 7./16 Matrix for the cutting device type UD-1000 for block cheese

and pressure is exerted pneumatically. After pressing, a raw cheese block is transferred to a cutting device (see Figure 7./16), where the raw cheese is cut into predefined dimensions. Then this cheese is manually transferred into so-called Perfora forms, which correspond to the dimensions of the preformed cheese, and then onto special trolleys. After charging these trolleys, the main pressing is done in tunnel presses, where a pneumatically controlled pressing cylinder presses each cheese individually. Figure 7./17 shows a partially mechanized line.



Picture 7./17 Process line of a partially mechanized hard and soft cheese line

(1) Cheese tank (2) Curd pump (3) Prepressing trough (4) Trolley with molds (5) Tunnel press

Completely mechanized processes. For capacities of 50–100,000 liters per day and more completely mechanized processes are economical and can have a more or less elevated level of automation. There are visible differences in equipment for lines of hard and soft cheese. Additional modifications are required for special types of cheese, e.g., Chester, Mozzarella.

Cubed block cheese is manufactured mainly on lines such as the one shown in Figure 7./17. After prepressing, the unit operations portioning, forming and transfer of the cheese to the tunnel press are automatic. For large cheese loaves such as Emmenthaler, forming assemblies (see Figure 7./19) are used, where the turning and the pressing (after placing the pressing cylinders) is done.

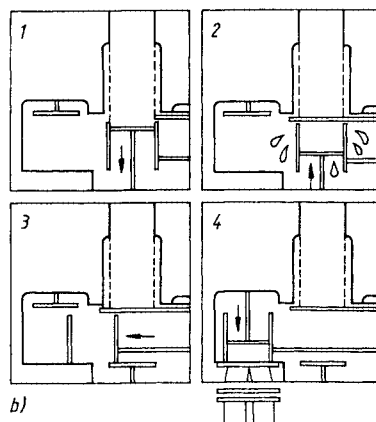
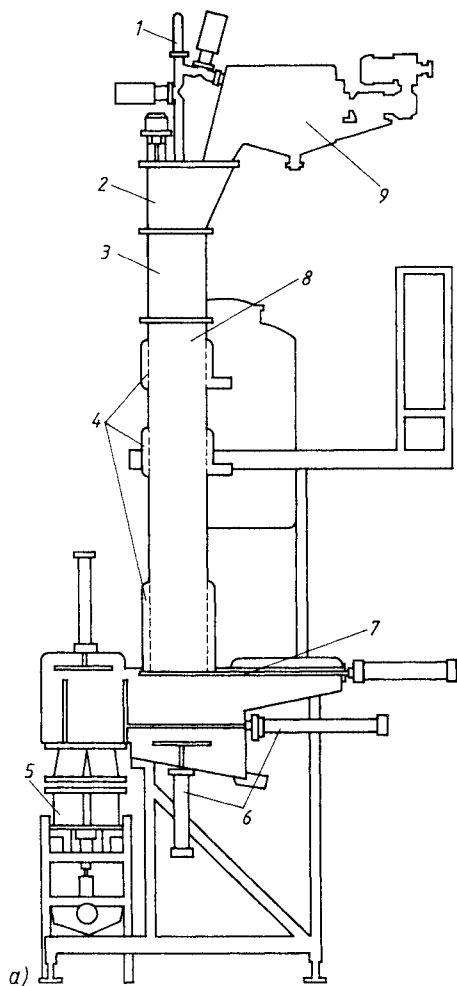


Figure 7./18
Scheme of a part of the whey and prepress battery type “Casomatic III”

- a) Total view
 - (1) Infeed of the curd/whey blend (ratio 1:3)
 - (2) Inlet funnel (3) Show glass (4) Sieve parts for whey separation (5) Cheese molds (6) Pneumatic lifting device (7) Column bottom, serves as a knife to portion the raw cheese (8) Product column (9) Sieve drum to separate whey from curd or to achieve a curd for soft cheese without post-pressing (e.g., Tilsiter)
- b) Working principle
 - (1) Lowering the curd column into a mold (2) Portioning and prepressing (3) Transfer of cheese mass to discharge device (4) Discharge of prepressed cheese into six working molds

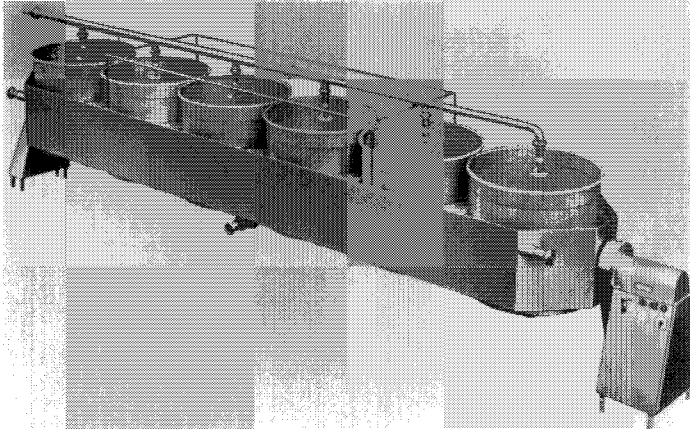


Figure 7./19 Battery with preinstalled sieves (ready for filling) in turning device for the manufacture of hard cheese in loaf form

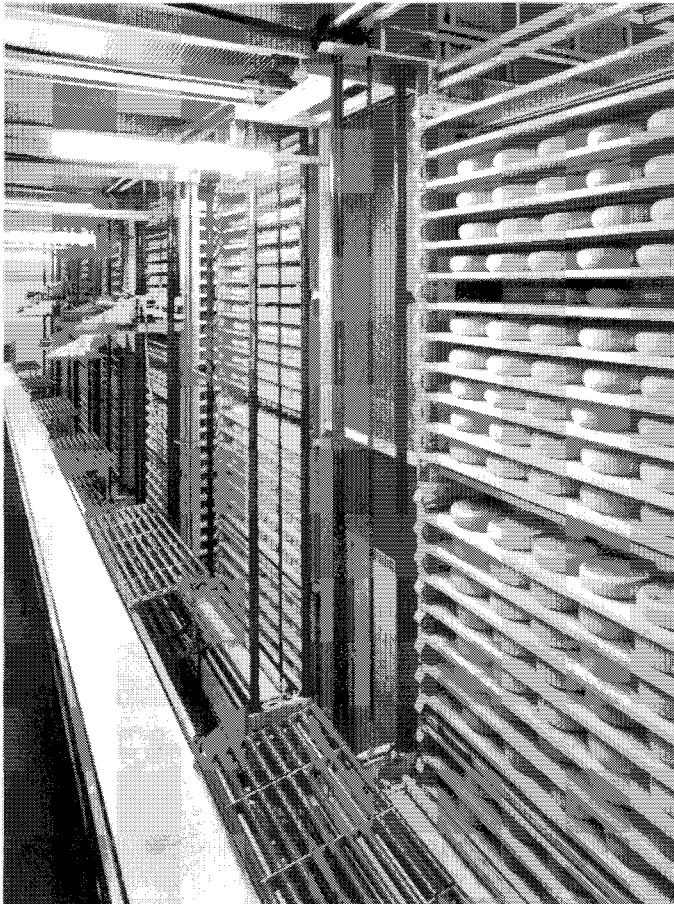


Figure 7./20 Automatically controlled ripening rooms for semisoft cheese

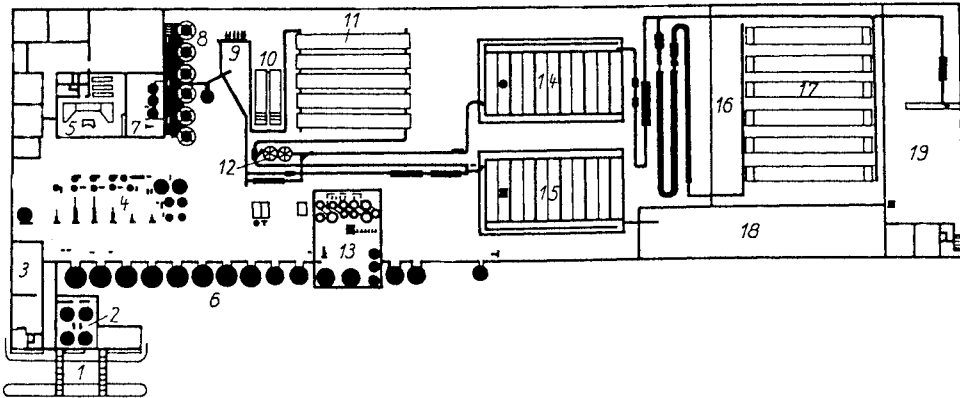


Figure 7./21 Layout for a completely mechanized cheese plant for round and block cheese

(1) Milk reception (2) Raw milk storage (3) Laboratory (4) Milk treatment (5) Control room (6) Silos for cheese milk storage (7) Culture preparation room (8) Cheese makers (9) Dewheying, prepressing and filling machines for round cheese (10) Prepress trough for block cheese (11) Tunnel press for main pressing (12) Intermediate storage for thermal time (13) Evaporator for whey utilization (14) Brine tank for round cheese (15) Brine tank for block cheese (16) Warm air tunnel for drying of cheese surface and section for prepackaging (paraffin coating or plastic bags) (17) Cheese storage for round cheese (18) Cheese storage for block cheese (19) Distribution

For the duration of the thermal time, cheese can be stored continuously in a silo-like intermediate storage, and the residence time is controlled by the conveyor belt speed. Thereafter the cheese passes through a brine tank, and after drying reaches the storage and ripening rooms (Figure 7./20). A completely mechanized semisoft cheese installation is shown in Figure 7./21.

Process for soft cheese. As soft cheese requires no or only minimal curd treatment, mechanized production processes can be designed for a continuous operation. Milk is transferred as a fixed, non-flowing entity in batches or segments without any mechanical shock, or subquantities are coagulated in the curd vessel in such a way that all later processes can take place continuously. Whey discharge happens on perforated belts or drums without subjecting the curd to mechanical stress. Portioning is done in forming batteries, where cheese is cut off from the product flow and is placed into the forms. Shaped portioning devices (chambers or drums) are used, which portion a certain volume into the molds in such a way that the cheese obtains its basic dimensions. Ensuing process steps take place in form boxes or stainless steel racks, which are transferred in assembled forms via conveyor belts to the individual processing stations, reaching the ripening rooms at the end. The required processing times can be maintained by controlling belt speed.

In Figure 7./22 a completely mechanized and automatic process line is shown, which shall be described below.

Standardized, tempered and preripened milk is stored in a tank (1) and is transferred by a pump (2) into a coagulator (4). This part of the process line consists basically of a semicircular conveyor belt with preformed molds, sliding on a water film with a shock-free movement and demarcated processing zones.

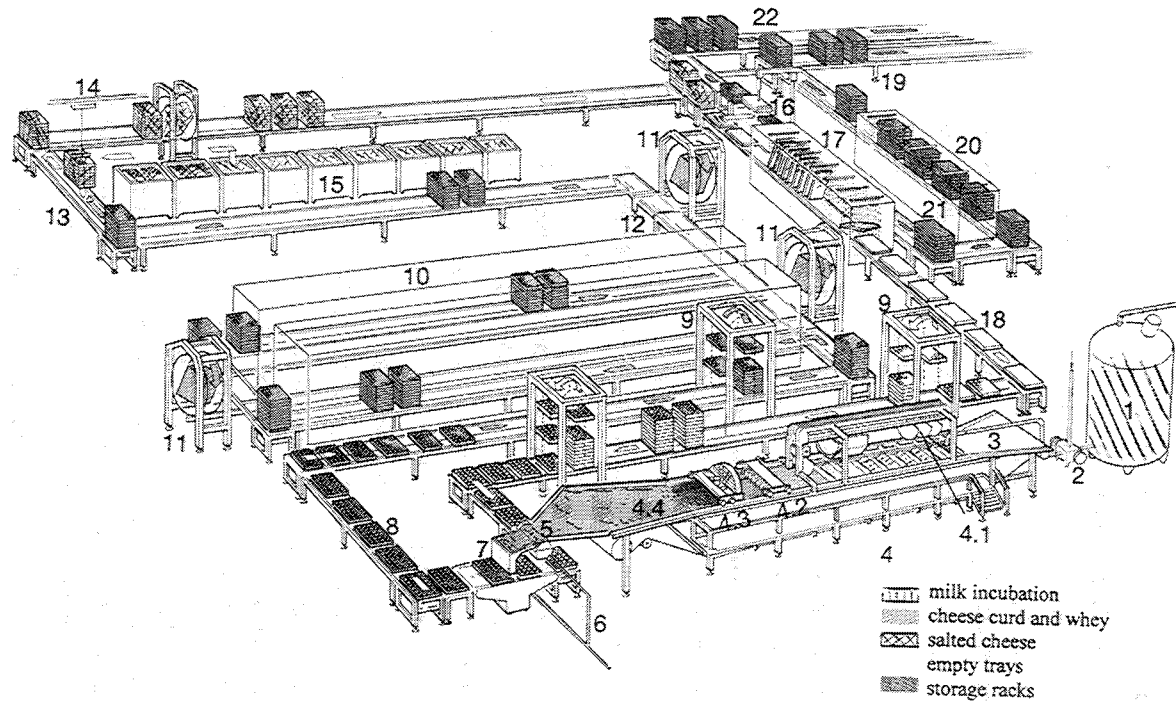


Figure 7./22 Process line for a completely mechanized soft cheese plant

(1) Continuous milk incubation (2) Milk pump (3) Milk inlet (4) Coagulator (4.1) Separating wall section (4.2) Longitudinal cutting station (4.3) Lateral cutting station (4.4) Syneresis section (5) Whey separation drum (6) Whey discharge (7) Portioning (8) Drainage section for molds (9) Chain stacking (10) Climatization tunnel (11) Stack rotation (12) Transfer conveyor (13) Drainage section for stacks (14) Lifting device (15) Brine bath (16) Cheese removal (17) Cleaning tunnel for forms (18) Transport conveyor (19) Cleaning trays from packing room (20) Cleaning installation for tray stacks (21) Tray preparation (22) Transport to ripening

After the inlet (3), milk reaches first a blending area, where coagulation enzymes and other additives are incorporated. By installing the partitioning walls, which are adjusted in their shape to the molds and permit a complete enclosure, milk is separated into zones and all movement is arrested for the ensuing coagulation. Coagulation takes place while the belt is moving completely shock-free. Before the longitudinal cutting, partitioning walls are removed automatically. A short-time electrical charge prevents adhesion of gel residues to the walls. Partitioning walls are then returned (4.1) and are cleaned in a separate cabin after each recycling. Cutting devices shape the gel into uniform cubes, whose dimensions can be adjusted by using different longitudinal inserts and by controlling the speed of the rotating vertical cutter. If required, a minor curd treatment can be done in the syneresis section by using paddles.

Pretreated curd can now be transferred to the dewheying belt or dewheying drum (5), where the major part of the whey is separated and removed (6). Curd passes through drum portioning devices (7) into the molds. Precise and gentle curd handling and portioning are ensured by the rotating dosing chambers. During filling of one dosing chamber, the opposite one is discharged (Figure 7./23), thus enhancing continuous product flow.

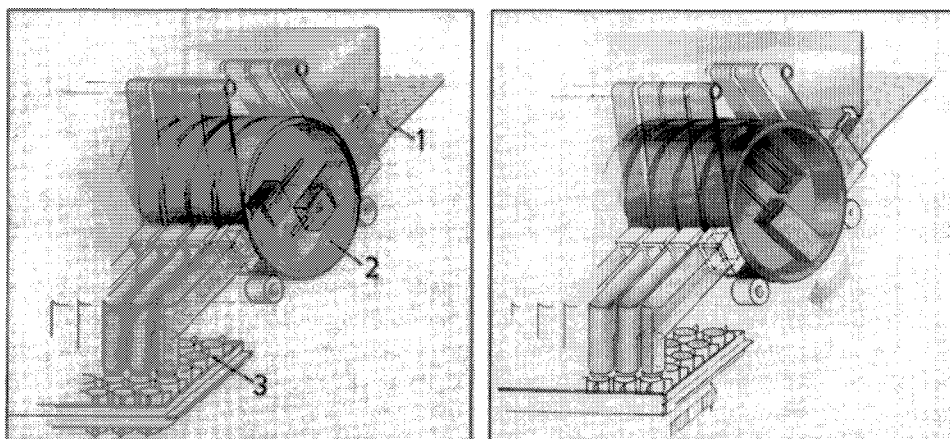


Figure 7./23 Operating principle of a drum portioning device

(1) Cheese curd (2) Rotating rings (drums) with dosing chambers (3) Molds

Block forms (Figure 7./24) are transferred from a cleaning station (17) via a conveyor belt (18), chain stacking and destacking device to a drum portioning installation. The filled form blocks are then transferred via a drainage section to a chain stacking unit, stacked, turned in a stack turning device (11) and finally transferred to a climatization tunnel. After one more turning the cheese passes through brine tanks (15), a drainage section and a mold removal station (16). Here the molds are removed and the cheese is then placed on the previously cleaned [in a washing station (20)] ripening stacks. Another conveyor belt transfers these stacks to the ripening rooms.

Process with continuous protein coagulation. This process is rarely used in cheese plants, because under normal conditions the milk has to remain static during the coagulation. Otherwise a uniform gel cannot develop, or significant protein losses and reductions in quality in the finished product must be anticipated.

Continuous protein coagulation requires suitable activities to reduce the coagulation time and to achieve a laminar or plug flow in the coagulation tubes. The following methods may be used:

- a) Strong preacidification to pH 6.0–5.9 and then coagulation
- b) Coagulation of low-acid milk and after passing through the enzymatic phase (see 7.3.2.1), addition of acid
- c) Cold coagulation, so that after the enzymatic phase immediate coagulation takes place in cold milk when preheated
- d) Enrichment of the dry matter level of milk by ultrafiltration before coagulation

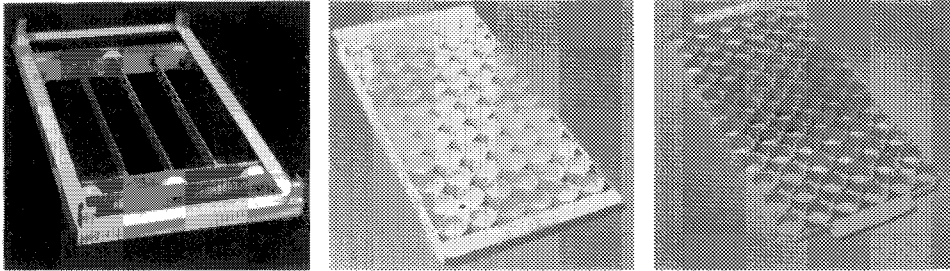


Figure 7./24 Stacking possibilities for molds

(1) Trolley (2) Mold blocks (3) Insert

7.3.11. Quality evaluation

The quality evaluation is done in two ways, by self-control by the dairy and the cheese storage and by an official evaluation by the authorities (state). This requires an organoleptic and chemical check. The quality grading is done after the official evaluation.

Organoleptic evaluation. Rennet cheese has many type-specific organoleptic properties and characteristics (Overview 7./7), which are the substance of the quality of the product. When a dairyman knows these properties, he can properly evaluate his product, recognize defects and avoid them. Apart from profound technical knowledge and know-how, he needs all his senses for a good organoleptic evaluation.

For an organoleptic evaluation, cheese is cut, or samples must be taken from larger loaves by using a cheese drill (Figure 7./25). The samples must be tempered to about 14 °C. According to IDF standards, the following properties are evaluated:

- a) Appearance/exterior—evaluation of, e.g., form, skin/rind, surface by visual check of the entire cheese.
- b) Appearance/interior—evaluation of, e.g., holes, color by visual evaluation of a cut surface or of a drill sample.
- c) Consistency/texture—evaluation on the basis of small pieces or a drill sample by bending, pressing and piercing between forefinger and thumb and by chewing.
- d) Flavor (aroma and taste)—flavor evaluation by smelling a cheese sample (cube or from drilling); for tasting, small samples are chewed.

These parameters do not always have the same value, as they depend on the type of cheese and the market situation. Criteria as mentioned in c) and d) have the greatest importance.

Grading into classes according to international standards is done on a point basis. For the four characteristics, points are given by the testing persons (average of the points of a testing person), added up and divided by four, and the classification is done accordingly:

Overview 7./7 Organoleptic characteristics and properties of rennet cheese

Group, type	Appearance, outer	Appearance inner (consistency, texture, dough, hole)	Taste and flavor
Hard cheese			
Emmenthalet	Firm yellow to brown rind with concave outer shape	Matte yellow, uniform holes, smooth dough	Mildly flavored, nutty
Chester (cheddar)	Completely closed surface	Light yellow to orange, slit-type holes, no brittle dough, melting on the tongue	Slightly acidic to spicy
Semisoft cheese			
Gouda	Dry and smooth rind with a white/gray-green fungus coating, no rind possible	Ivory to yellow, matte, round to oval holes (pea-sized), even distribution in dough, not numerous, firm to smooth dough	Mild to slightly spicy
Edam	Dry and smooth rind with a white/gray-green fungus coating, no rind possible	Ivory to yellow, mat, round to oval holes (pea-sized), even distribution in dough, not numerous, firm to fatty dough, softer than Gouda	Mild and clean, non-acidic
Tilsiter	Dried on wet coating, also washed after ripening, also without rind	Ivory to light yellow, slits and holes (grain size), and round holes. Smooth dough, not short or brittle	Slightly bitter to spicy, slightly acidic but not sour
Semisolid semisoft cheese			
Steinbuscher	Yellow-brown to red, little smear	Ripened dough is yellow, few curd holes, smooth dough	Mild to slightly spicy
Mold-ripened	Visible holes for mold growth	White to yellow color, dough contains veins of dark-green or blue mold streaks, slightly brittle but still smooth	Spicy to very spicy
Butter cheese	Smooth skin yellow to red, also without rind	Cut surface has yellow color, dough without holes, dough semi-solid to firm, uniformly ripened throughout	Mild to acidic traces
Weisslacker	White-yellow surface, covered with a low viscosity smear	Wight cut surface, few curd holes, no holes in the dough, uniformly ripened	Very spicy to hot
Soft cheese			
Camembert	Uniformly covered with Camembert mold, on the outside some red smear possible	Color of dough white to creamy yellow, in the dough a few curd holes, no other holes, ripened dough is smooth	Mildly aromatic
Brie	Uniformly covered with Camembert mold, on the outside some red smear possible	Color of dough white to creamy yellow, in the dough a few curd holes, no other holes, ripened dough is smooth	Aromatic, slightly acidic to spicy
Romadur	Smooth skin with yellow-brown to red smear	Cut surface of dough is matte white, ripened mass yellow, in the dough only few curd holes, soft dough, but not flowing	Mild to slightly spicy
Limburger	Smooth skin with yellow-brown to red smear	Cut surface of dough is matte white, ripened mass yellow, in the dough only few curd holes, soft dough, but not flowing	Spicy to piquant
Muenster	Yellow-red smear with good skin formation	Cut surface white yellow color, smooth and closed dough	Mild and clean

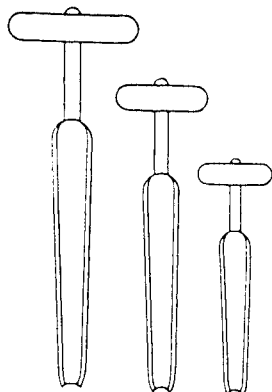


Figure 7./25 Cheese drills, which are also used for block butter sampling.

IA (“Prime A”/“Extra”/“Super”)	4.50–5.00 points
IB (“Prime B”/“Regular”/“Standard”)	4.00–4.49 points
II (“Second”)	3.50–3.99 points
III (“Third”)	<3.50 points

The German cheese regulation (“Käseverordnung”) uses the following grading system:

Appearance—exterior	max. 5 points
Appearance—interior	max. 5 points
Consistency/texture	max. 5 points
Flavor	max. 5 points
Taste	max. 5 points

If rennet cheese shows the characteristics in Table 7./7, then 5 points are given; otherwise deductions are made depending on the severity of the deviation.

Chemical evaluation. Chemical evaluation is done for the fat content, dry matter content (*DM*) (can be derived from the moisture content) and the salt content. Fat content in dry matter is calculated as follows:

$$\text{Fat (dry matter)} = \frac{\text{Fat} \cdot 100\%}{\text{Dry matter}}$$

Minimum dry matter content, fat in dry matter and moisture content of the nonfat cheese mass of the individual types of cheese can be seen in Overview 7./1.

Quality grading. According to the official grading system, German cheese can be graded as “Markenkäse” (“quality grade”), if the following results are obtained:

- Fat in dry matter $\geq 40\%$
- compliance with the indicated fat content or the labeled minimum fat content
- minimum 4 points in the organoleptic evaluation

Cheese defects. Some of the major cheese defects and their causes are shown in Overview 7./8.

Overview 7./8 Cheese defects

Defect	Cause
Exterior	
Water discharge	Coagulation temperature too low, insufficient rennet, curd too soft, ripening rooms too warm
Skin cancer	Black fungus, <i>Penicillium brevicaulis</i> , caves too humid
Yeasty	Strong yeast population, insufficiently heated cheese milk, improper practices, non-cleaned tools, infected brine
Foreign mold	Mainly in mold cheese by contamination with a cave fungus (<i>Penicillium commune</i>) or <i>Mucor</i> types, which enter via the cultures, tools (trays) or ambient air
Interior	
Gas formation	Early gas formation by coliform bacteria or lactose yeast, late gas formation due to clostridia; bad feed, unhygienic work practices
Irregular holes	Improper curd treatment, improper turning
Cracks	Curd too acidic
Soft in outer regions	Insufficiently ripened cheese milk, whey content too high, low enzyme dosage, insufficient salting (curing), ripening temperatures too high, contamination with proteolytic germs
Taste and flavor	
Whey sour	Whey content too high, cheese milk heated too much, insufficient curd treatment
Bitter	Bad feed, whey content too high, coli gas formation, enzyme dosage too high, low brine quality, improper ripening profile, especially with laminate ripening
Salt sharp	Curing too early, salt uptake too high due to long curing, brine concentration too high and too warm

7.3.12. Rennet cheese yields

The objective of each cheese plant is to manufacture cheese of good quality, under economical conditions, i.e., to have a favorable ratio between milk quantity and profit. This ratio is also described as yield.

- Yield indicates how many kg of cheese (in a form ready to distribute) have been obtained from 100 kg milk.

Sometimes the specific milk consumption is indicated as yield.

- The specific milk consumption is the amount of milk required to manufacture 1 kg of cheese ready for distribution.

It is very difficult to determine the actual yield, as many rennet cheese types reach their final ripening stage after weeks, sometimes months, and only then can the final weight be determined. In order to have an actual Overview, approximate values are used, from which the targeted yield is calculated. These target yields can then serve as a basis for process modifications and for economic calculations. The yield depends mainly on these factors:

- a) Composition of milk, especially the content of protein that can be converted into cheese and the content of minerals
- b) Content of fat and protein, which are converted into cheese during its manufacture
- c) Final moisture content of the cheese

- d) Material uptake during the production and handling of cheese, e.g., salt uptake, absorption of spices

The determination of fat and protein in cheese milk is relatively easy. Fat which is transferred into cheese in the form of the net fat content f_N in % is the difference between the fat content in cheese milk f_{cm} and the average fat content in whey f_{whey} .

$$f_N = f_{cm} - f_{whey}$$

The protein utilization rate between milk and cheese is 75%; the moisture content is 50–80% and therefore has a considerable influence onto the cheese mass. Schulz and Kay have developed relations for calculating the target yields between the moisture content of the nonfat cheese mass W_{ff} , the water-soluble salts (milk salts, salt) and the migrating protein (from milk into cheese) and have established a factor F . The target yield TY can be calculated by using the protein content of milk pc in %, the net fat content f_n in % as follows:

$$TY = f_n + f \cdot pc$$

The factor F can be calculated in a different manner:

$$F = 0.75 + \frac{0.825 \cdot W_{ff}}{100 - 1.1 \cdot W_{ff}}$$

Table 7./8 Water content of nonfat cheese mass and protein conversion factor

W_{ff} in %	F	W_{ff} in %	F
50	1.67	61	2.28
51 (Emmenthaler)	1.71	62 (mold-ripened cheese)	2.36
52	1.75	63 (Steinbuscher)	2.44
53	1.80	64 (Limburger)	2.53
54	1.85	65 (butter cheese)	2.63
55	1.90	66 (Romadur)	2.73
56 (Chester)	1.95	67 (soft cheese)	2.85
57	2.01	68 (Camembert, Brie)	2.98
58 (Gouda)	2.07	69	3.11
59 (Edam)	2.14	70	3.25
60	2.20	71	3.39
		72	3.54

7.4. Fresh cheese

The following definition is used for fresh cheese, which also known as unripe or non-ripened cheese:

- Fresh cheeses are products with different fat content levels, manufactured from pasteurized milk, cream or skim milk by acidification of lactic acid bacteria and/or rennet reaction, where protein (derived from its whey) can be added into (maximum 18.5% of total protein). It is commercialized fresh, i.e., without ripening. Fat content can be set even after the whey discharge,

The exclusion of ripening is related to proteolytic reactions, which take place during the main ripening of rennet cheese. Certain ripening processes do take place during the lactic acid fermentation.

Fresh cheeses can be distinguished as per their appearance and consistency into

- a) Paste (quarg, cream fresh cheese)
- b) Grainy (cottage cheese) and
- c) Firm to solid (layered cheese)

and the type grading is done accordingly. Further we should mention fresh cheese preparations.

- Fresh cheese preparations are blends of quarg, cream fresh cheese, double cream fresh cheese or cottage cheese with fruits, spices or herbs or other foods, whose part does not exceed 15% of the total product; for fruits and vegetable preparations 30% is permitted. For shelf life extension, these products can be submitted to a heat treatment, and binding agents can be added for stability.

The most widely known fresh cheese is quarg, (also known in Germany as “Topfen” or “Weisskäse”); its production will be described in detail. Fresh cheese products are manufactured with a sweet or spicy flavor by using corresponding additives, and there are numerous combinations. Besides cream fresh cheese and double cream fresh cheese, descriptions of the manufacturing process for buttermilk quarg, layered cheese and cottage cheese will be given.

7.4.1. Fresh quarg

In the manufacture of quarg, as well as for other quarg products, we have typical unit operations such as selection and pretreatment of milk, acidification and protein coagulation, separation or concentration, refrigeration, packing and storage. Additional operations such as fat standardization and heat treatment (for shelf life extension) are required. Key unit operations are separation of the curd/whey blend (after the protein coagulation) and concentration of the dry matter content and the protein content to the desired target values. Unit operations and their processing parameters are designed in view of the separation/concentration step. This is valid especially for the thermal unit operations such as heat treatment of cheese milk and possible thermization of the curd/whey blend. We therefore use the terms “standard process” (having a classical temperature profile) and “thermization process” (having a specific heat treatment for the milk and curd/whey blend).

7.4.1.1. Selection and pretreatment of milk

For the production of fresh cheese, milk does not have to meet the same high quality requirements as for cheese milk, as the microbial processes are limited to lactic acid fermentation. However, bad raw milk cannot be transformed into a high-quality finished product. This applies especially to the absence of inhibitors and a good acidification potential.

Preheating of the milk is an important process parameter, as this leads to sufficient denaturing of the whey proteins. In contrast to the rennet cheese products, for which whey proteins are a disturbing factor for processing and ripening, migration of the whey

proteins into the fresh cheese is advantageous in many ways. Above all, the water binding capacity of the gel and its firmness is improved, syneresis is reduced and the yield is increased, which is of economic interest.

A short-time heat treatment, required by law, is normally insufficient to achieve a sufficient degree of denaturing. Only at higher temperatures and longer residence times, whey proteins and casein enter into the desired complex reactions. Therefore a high-temperature process, which can be modified toward higher levels, is advantageous. The optimal time-temperature combination is said to be 90 °C and 15 min holding time or 95 °C and 5 min holding time.

- The optimal pretreatment for milk used in fresh cheese production consists of a double heat treatment.

Fat standardization is done mostly in the concentrated quarg, less in cheese milk, in order to reduce fat losses through the whey.

7.4.1.2. Acidification and protein coagulation

The acidification profile and final pH significantly determine the organoleptic quality of the finished product. On one hand, a typical acidic taste and the typical flavor are formed, on the other hand, the level of bound or colloidal solubilized calcium is reduced. An increased calcium content mostly leads to taste defects such as “bitter” and “gluey.”

Quarg is classified as a rennet cheese, as during the coagulation the percentage of the enzymatic reaction is 5–30% (rennet cheese 50–100%).

During acid coagulation calcium ions split off from the casein and are formed into the more soluble calcium lactate. The calcium content in rennet cheese is lower (0.6–0.9%) than that in rennet cheese (1–2.5%). The main purpose of the enzyme addition to fresh cheese is to accelerate protein coagulation and to firm up the coagulate. This reduces protein losses and improves yield. On the other hand, this enzymatic reaction must be kept under control, as the typical enzymatic proteolysis is not desired.

During the acidification process (after the protein coagulation), calcium lactate forms, so that the calcium bridges are dissolved from the rennet gel and the curd becomes similar to a pure acid casein at the isoelectric point (large porosity).

The starter culture is normally a blend of pure lactic acid microorganisms; there are fewer flavor developers. The added quantity varies between 0.3–4% and is subject to the type of culture, acidification potential of milk, acidification temperature (the higher the temperature, the less culture is required) and curd separation process.

- Culture addition and acidification profile must be controlled in such a way that after about 1.5 hours milk has reached a pH of 6.3 (for adding the enzymes) and coagulation is finished after about 16 hours at a pH of 4.5–4.55.

As coagulation enzymes, blends of rennet and pepsin are used (3–7 g per 1000 l milk) or liquid rennet in a strength of 1:10,000 (5–20 ml per 1000 l milk). If milk has been treated with the high-temperature process, then 500–800 ml of a solution of calcium chloride per 1000 l milk is added in order to improve the coagulation potential.

7.4.1.3. Concentration/curd separation

Concentration to the desired dry matter content for quarg (17–20%) and a protein content of 12.5–13.5% (for low-fat quarg) or separation of gel into whey and quarg can be done by the following processes:

- a) Batch separation by pressing or drainage by using filter cloth or filter bags
- b) Continuous centrifugation using quarg separators
- c) Continuous concentration or separation by ultrafiltration

Processes under a) are traditional and are used only for the processing of residual quantities of milk or sometimes for the production of fresh cheese with a higher dry matter content ($\geq 21\%$), as these processes are very labor intensive and do not offer a reliable level of quality.

Currently, the most widely used process is the curd separation using quarg separators (see 7.4.1.3). Under normal processing conditions i.e. curdling temperatures in the range of 26–28 °C, a dry matter content of $\leq 20\%$ can be achieved. An additional increase in dry matter content can be obtained by heating the curd immediately before the separation; then curdling temperatures of 20–22 °C can be used, thus avoiding possible overacidification of the quarg. This so-called thermo-process or thermo-quarg process results in an increase of the dry matter content and an increase in yield. It will be described in detail below.

Thermo-quarg-process (Figure 7./26). Raw milk is decreamed in a separator (6) at 50–55 °C. Skim milk is transferred to a plate heat exchanger (4), where it is heated and held in the tubular holding section (5). It then passes again through a plate heat exchanger (4), where by exchanging heat with the cold raw milk and with cooling water temperature is reduced to 28–30 °C, the acidification and coagulation temperature. Once milk has been coagulated in the tank (7) and curd is treated by the stirrers, this curd/whey blend is transferred by a centrifugal pump (8) through a buffer tank (9), another centrifugal pump (10) to a plate heat exchanger (1), where it is heated up to 60–64 °C, and held in holding tubes (12) for 4–6 minimum.

Separation temperature of 40–44 °C is obtained by heat exchange with the nonheated curd in a plate heat exchanger (11), where a temperature of 35 °C is reached and temperature equalization between heated and nonheated curd is controlled by the volume flow, while keeping the separation temperature constant. Tubular sieves (13), operating in turns, prevent too large protein or other particles reaching the separator and block the nozzles (ports).

A quarg separator (15) (a cutaway is shown in Figure 7./27) is similar to a decreaming separator (see 4.2.3.4 and Figure 4./13), but the bottom part of the bowl is equipped with a variable number of nozzles (ports) which discharge the quarg continuously. A separator type as shown has 12 ports in the periphery of the drum. Each has a diameter of 0.6 mm, and can discharge about 150 kg quarg/h, resulting in a total flow of 1800 kg/h. The tempered curd/whey blend goes through a central inlet pipe into the bowl and is then distributed into the rising channels of the disk assembly. Whey flows through the gaps between the disks to the center of the bowl, is directed toward the top and is then discharged foam free via a paring disk. The separation effect can be visually observed in a side-glass of the whey discharge line by evaluation of the whey turbidity, and process and material parameters can be adjusted accordingly. The heavier protein is transferred to the conical bowl periphery. It is discharged by ports into the ice water-chilled lid and the concentrate collector and finally into the quarg funnel. The quarg pump is controlled by a level sensor, installed in the quarg funnel. Once separation has taken place in the quarg separator,

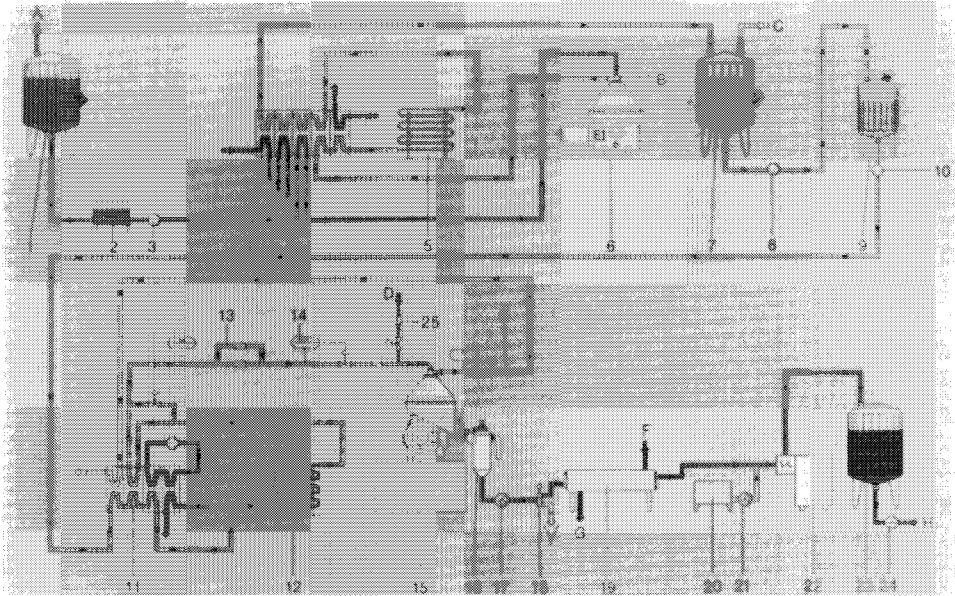


Figure 7./26 Process line for thermo-quarg process

A Raw milk inlet **B** Cream discharge **C** Starter culture and lab addition **D** Water addition **E** Whey discharge **F** Ice water inlet **G** Ice water outlet **H** Quarg for filling

(1) Raw milk tank (2) Buffer tank (3) Centrifugal pump (4) Plate heat exchanger (5) Tubular holding section (6) Decreaming separator (7) Cheese milk tank (8) Centrifugal pump (9) Buffer tank with stirrer (10) Centrifugal pump (11) Plate heat exchanger (12) Tubular holding section (13) Tubular sieves, switchable (14) Flow control (15) Quarg separator (16) Quarg funnel (17) Displacement pump (18) Switching valve (19) Quarg chiller (20) Cream tank (21) Displacement pump (22) Quarg mixer (23) Quarg silo (24) displacement pump (25) Tubular sieve

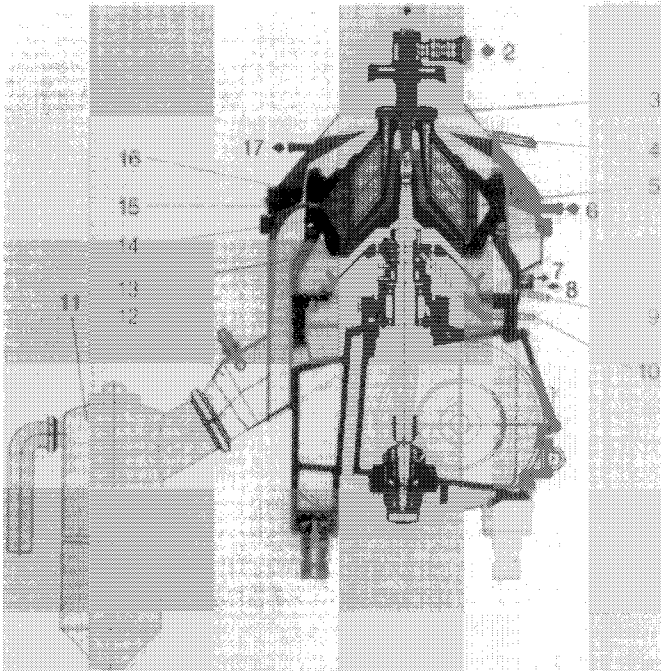


Figure 7./27 Quarg separator, type KDB 30

(1) Inlet (2) Whey discharge (3) Whey paring disk (4) Upper overflow (5) Insert (6) Lid cooling, inlet (7) Discharge for concentrate collector and brake ring cooler (8) Inlet for concentrate collector and brake ring cooler (9) Frame, discharge (10) Sterile air/CIP connection (11) Quarg funnel (12) Concentrate collector (13) Chilled brake ring (14) Rising channel (15) Disk assembly (16) Discharge lid cooling

whey is transferred to a plate heat exchanger (11) in order to preheat the curd and for discharge. Quarg goes from the funnel (16) via a displacement pump (17) into a quarg chiller (18), where it is precooled to 16–18 °C, into a mixer (22) and finally into a quarg silo (23). During start-up and shutdown, the separator bowl is filled with water through a pipeline having a tubular sieve (25).

Concentration by ultrafiltration. The utilization of the ultrafiltration during manufacture of quarg has gained in importance, as it allows better separation and a very good yield. Specific milk consumption, which is indicative, is in the range of 3.2–3.4 kg skim milk per kg finished product (specific milk consumption of other processes is in the range of 4.5–6.0 kg/kg). Further, energy requirements are lower than those for separators but installation costs are higher. Key parameters for the three processes are shown in Overview 7./9.

Overview 7./9 Material and process parameter for quarg manufacturing

Process	Continuous curd separation with separator	Continuous concentration by UF	Batch-type curd separation with filter bags
Preheating and holding	Only partial application same as UF	95 °C, 5 min	—
Setting the acidification or coagulation temperature	27–30 °C, the higher the temperature the higher the dry matter and the yield	20–22 °C (26–28 °C)	18–24 °C
Preacidification and preripening	2–3 h, until pH 6.4–6.5	2–3 h at pH 6.4–6.5	1–3 h to pH 6.4–6.5
Acidification and coagulation	27–30 °C, 13–15 h	20–22 °C, 16–17 h (26–28 °C, 14–15 h)	18–24 °C, 15–20 h (after 6 h, gel is cut into cubes of 6 cm)
Curd treatment	Stirring in the tank at pH 4.5 for curd (whey SH 26–28)	Stirring in tank at pH 4.6 for curd	After cutting whey discharge, then no more cutting
Curd separation or concentration	With separator at 27–30 °C (40–50 °C after curd heating)	With UF plants at 37–40 °C, concentration 1:3.1–1:3.4	In bags or filter cloth by gravity or additional pressing, multiple turnover of bags
Cooling of quarg, fat standardization	< 5 °C in heat exchanger after separation and cooling by blending of cream	< 5 °C in heat exchanger after UF and cooling by blending of cream	< 10 °C in cold storage
Dry matter of quarg	19–20%	17–19%	20–30%
Consistency	Fine, paste, easy to transfer and fill	Fine, paste, creamy, easy to transfer and fill	Coarse, sometimes milled or finished for consistency improvement

Quarg manufacture by ultrafiltration is possible by the following processes:

- Preconcentration of milk to target dry matter, followed by acidification and coagulation
- Concentration of the traditionally acidified and coagulated milk (Figure 7./28)
- Partial concentration of whey by ultrafiltration after separation and adding the separated protein back into quarg (Figure 7./29).

Preconcentration of cheese milk by UF installations permits higher efficiency (reduced deposits in the membranes, higher flow rates), and the desired product quality is

not obtained in most cases. Reasons are the elevated calcium level and a modified acidification profile. Good quality with favorable economics and operating conditions is obtained by process developed by Kessler et al., using complete concentration of the traditionally coagulated milk. Up to a concentration level of 1:2.2 the product can be transferred by centrifugal pump. Product transfer at a higher concentration level (e.g., 1:3.4) until reaching the final quarg dry matter level is done by displacement pumps.

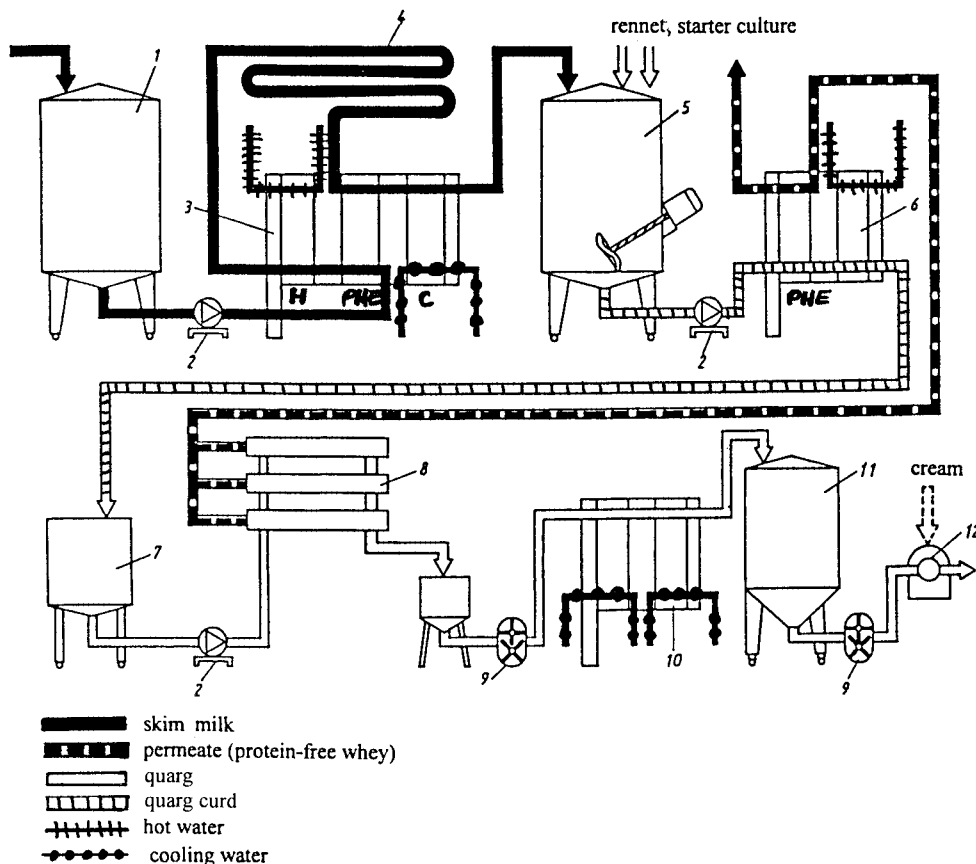


Figure 7./28 Flowsheet for a UF concentrate process

(H) Heater (PHE) Plate heat exchanger (C) Cooling section

(1) Storage silo for treated skim milk (2) Centrifugal pump (3) Plate heat exchanger PHE to pre-heat milk (4) Holding section (5) Coagulation tank (6) PHE for curd and permeate tempering (7) Buffer tank (8) UF plant (9) Displacement pump (10) PHE for quarg cooling (11) Quarg tank (12) Mixer for fat standardization

Similar product qualities are obtained by variant c), but it requires more equipment (UF plant and separator). The whey, which is removed by the separator, having a dry matter content of 6.0–6.4% is concentrated to a degree of 1:18–1:20 in UF plants, so that a whey protein concentrate with a dry matter content of 17–18% is manufactured. This concentrate is heated up to 90–95 °C, held for 2–5 minutes, homogenized, cooled to 30 °C, and then added back into the quarg (leaving the separator). Then cooling, intermediate storage, mixing and filling are done.

- UF plants used for milk protein concentration must be designed for continuous operation in the pH range 2–11 and temperatures > 65 °C, as well as for reagents in the same pH range and temperatures < 80 °C for chemical cleaning and disinfection.

If the concentrate (retentate) is obtained at temperatures < 55 °C, it requires an additional heat treatment.

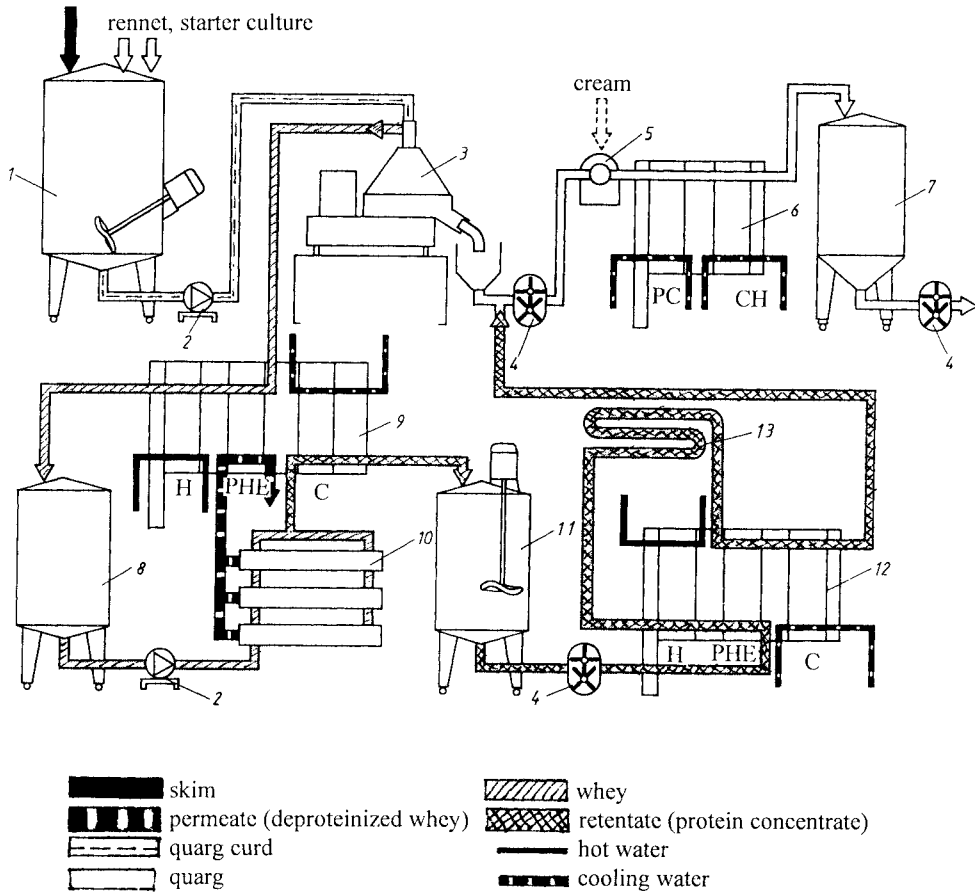


Figure 7.29 Flowsheet for the UF partial concentrate process (for whey separation, for quarg UF process)

(H) Heating (PHE) Plate heat exchanger (C) Cooler (PC) Precooler (CH) Chiller
 (1) Coagulation tank for processed skim milk (2) Centrifugal pump (3) Quarg separator (4) Displacement pump (5) Mixing unit for fat standardization (6) Plate heat exchanger (7) Quarg tank (8) Whey tank (9) PHE for whey, permeate and retentate processing (10) UF plant (11) Tank for protein concentrate (retentate) (12) PHE for retentate heating and cooling (13) Holding section

7.4.1.4. Chilling of quarg

The purpose of cooling is to stop propagation of the typical microflora and avoid recontamination as well as overacidification of quarg. This will effectively counter product defects such as “yeast-like,” “fermented,” “vinegar-sour.”

- Quarg must be cooled down immediately after manufacture, and a temperature of < 5 °C must be achieved as rapidly as possible and maintained until distribution.

A two-stage cooling can be favorable. In the first stage, the product is cooled immediately after continuous manufacture to a temperature of 14–18 °C; the second stage is done immediately before filling. Here the final temperature is reached and an improvement in consistency in the pack can be observed.

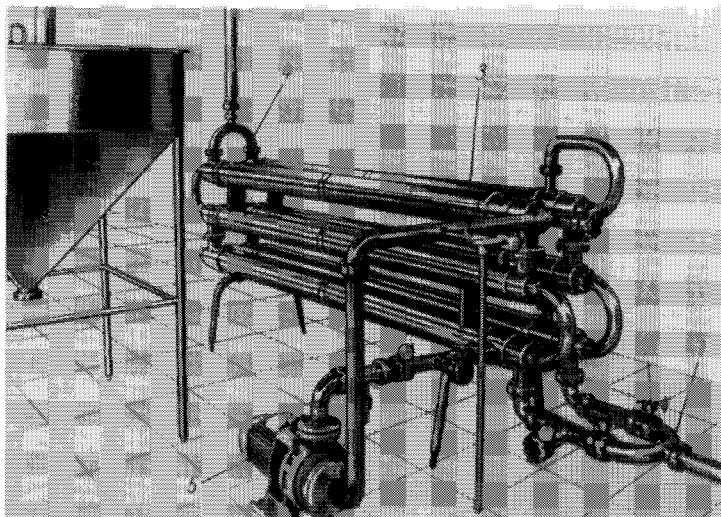


Figure 7./30 Tubular heat exchanger, type RK 2/3. Flow rate 1000 kg/h, quarg inlet temperature 30 °C, quarg outlet temperature 5 °C, ice water flow rate 12,000 l/h, required energy 97 MJ/h, pressure drop 3.6 bar

(1) Product inlet (2) Throttle valve (3) Tube elements (4) Product outlet (5) Cooling water circulation pump

Plate heat exchangers are less suitable, as the turbulent currents which make these installations so effective cannot be achieved due to the high viscosity involved. Tubular heat exchangers are more suited for this task. The installation shown in Figure 7./30 shows six elements linked to each other. In an outer tube, there are two smaller tubes with different diameters, so that there are two annular gaps between the tubes. The innermost and outer gap contain ice water, whereas the center tube contains the product.

7.4.1.5. Fat standardization/fat exchange

When manufacturing a fatty quarg by using a quarg separator, fat standardization in cheese milk is unsuitable, as too much fat would be transferred into the whey during the separation process. Therefore cream is added to the quarg after separation. In some separator types, cream dosing takes place in the separator immediately after quarg has left the separator bowl. In another more common process, fat standardization is done by a continuous mixing, using a dosing pump for adding cream. With such a blending installation, other additives can be incorporated during the manufacture of quarg products.

The cream quantity must be calculated correctly to minimize fat losses and achieve the targeted quality. The following equation is used:

$$m_c = \frac{m_q \cdot DM_q \cdot FiDM}{100\% \cdot f_c - FiDM \cdot DM_c}$$

m_c	cream in kg
m_q	quarg in kg
DM_c	dry matter of cream in %
DM_q	dry matter of quarg in %
f_c	fat content of cream in %
$FiDM$	fat content in dry matter of finished product in %

Up to an FiDM of 50%, the cream addition can be calculated approximately, using empirical formulas. A factor of 6 is used for the specific milk consumption per kg quarg, and a cream fat content of $\geq 30\%$ is assumed:

$$FiDM 50\%: m_r = \frac{DM_q}{f_c - 6} \cdot m_q$$

$$FiDM 40\%: m_r = \frac{DM_q}{1.5 \cdot f_c - 6} \cdot m_q$$

$$FiDM 30\%: m_r = \frac{DM_q}{2.33 \cdot f_c - 6} \cdot m_q$$

$$FiDM 20\%: m_r = \frac{DM_q}{4 \cdot f_c - 6} \cdot m_q$$

$$FiDM 10\%: m_r = \frac{DM_q}{9 \cdot f_c - 6} \cdot m_q$$

In the case of continuous dosing, the quantity of quarg is replaced by the flow rate of quarg, and the amount of cream is then replaced by the cream flow rate (in kg/h). The main purpose of fat addition is texture modification, i.e., an improvement in taste and structure. The increase in the energy content of the product is a secondary nonintentional effect; in many cases the higher fat content is perceived negatively.

A positive texture modification in low-fat or nonfat quarg products can be achieved by adding micromilled whey protein, as done with the product "Simplese®100" (see 5.2.2). An addition of even 5% of this ingredient leads to a texture equivalent to that with a fat content of 30–40% in FiDM. This addition has to comply with the food legislation, especially labeling. In case of complete fat replacement or substitution, the product would become a "substitute" and must be labeled accordingly. A quarg product can have a maximum content of 18.5% of these additives (whey protein) and can still be called a quarg product.

7.4.1.6. Preservation

Quarg is destined for a quick consumption, but shelf life can be extended by non-conventional methods which are not typical for standard process. Conditions in the cold chain are not always optimal, and longer distances and times must be covered due to product concentrations and market expansions. Consumer demand for fresh products with an

extended shelf life is the result of “improved” storage and a good product quality over a longer time.

The objective is to achieve shelf lives for quarg products of 10–30 days at ambient temperatures (15–20 °C). If the storage temperature is kept < 10 °C, then the shelf life can be extended to 4–6 weeks. For this the following processes can be used:

- a) Aseptic production under sterile conditions
- b) Chemical preservation
- c) Thermal preservation

Aseptic production under sterile conditions requires a high investment in machines and equipment and results in high production costs. Products manufactured in such a way keep their initial quality as well as their initial nutritional value.

Chemical preservation. Officially authorized chemical preservatives should be used only sparingly. These chemicals are justified only if they result in additional technological, economical or other effects which cannot be achieved by normal physical processes. A toxicological reaction in the human body cannot be excluded entirely, as reactions can occur in both the micro- and macroorganism. The antimicrobial effect is caused by (see also 11.4.3):

- a) Blocking of the permeability of the cell membrane
- b) Disruption of the enzymatic systems
- c) Protein coagulation in the cell
- d) Blocking of metabolic reactions

The objective is not always a bactericidal or fungicidal effect; sometimes a bacteriostatic or fungistatic effect is sufficient.

- When using chemical preservatives, the minimal amount which has the desired effect should always be used.

In general, prevailing food laws, which indicate the type and concentration of the chemical preservative must be complied with. The following chemical preservatives are suitable for the preservation of fresh cheese or the preservation of surfaces of certain types of rennet cheese irrespective of legislative approval:

- a) Sorbic acid and its salts (e.g., potassium sorbate)
- b) Benzoic acid and its derivative sodium benzoate
- c) Parahydroxybenzoic acid ester (PHB)
- d) Formic acid and its salts, e.g., sodium formiate or potassium formiate

The maximum applicable amounts are, e.g., for sorbic acid and its salts 2 g per kg product. For surface preservation, solutions with a maximum of 2% are used.

Thermal preservation. Thermal preservation, i.e. the heat treatment by thermization (second pasteurization; see 4.2.7.2 and Overview 4./4) the most common process, as they are economically justified, can be handled well from a technological point of view and is safe for quality. The time-temperature profile depends on product quality, above all pH value, dry matter content, fat content and microbial inactivation effects.

- Thermization of quarg and quarg products is done at 55–75 °C for 30–60 s.

For normal, nonstabilized quarg or quarg products with up to 40% dry matter, the limits for thermization are $\text{pH} < 4.2$ and heating temperatures $< 60^\circ\text{C}$, otherwise the protein coagulate would become too firm and taste defects such as “sandy” would develop. The achieved inactivation effect of 60–70% is sufficient for a shelf life extension, the very low pH, however, can cause a very acidic taste.

Thermal preservation can be done either by heating the curd, as done with the Thermo-quarg process (and described in 7.4.1.3), or by thermization of quarg followed by a hot filling or an aseptic cold filling. Stabilizers are added during quarg thermization.

Thermization of quarg products is done in universal blenders (Figure 7./31), where the additions can be distributed uniformly. The product is filled into a bowl, which can be heated and cooled and is equipped with stirrers and scraping devices for blending and disintegration. Heating is done indirectly, but can also be done directly by steam injection ($p_{\text{steam}} < 1.5 \text{ bar}$) and can operate under a vacuum due to the airtight lid. Gases for foaming purposes can be injected into this vessel too. The total cycle time is 2–5 minimum subject to the size of the bowl, quantities up to 130 kg per batch can be processed.

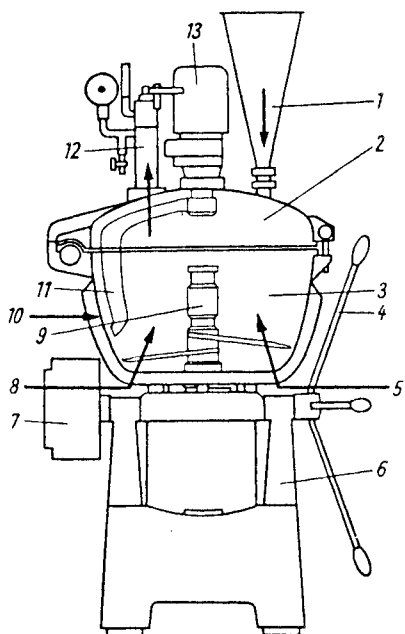


Figure 7./31
Universal batch mixer with tempering device, type UMM/SK

(1) Dosing device (2) Cover with closing device (3) Bowl (4) Lever for tilting (5) Direct heating or cooling (6) Frame with drive motor (7) Compressor for compressed air for valve control (8) Injection of gases (9) Elongated shaft with cutting devices (10) Indirect heating system/cooling system (11) Stirrer with scraper (12) Vacuum and condensation device with aeration and deaeration installation (13) Drive for scrapers

For a continuous thermal process, a tubular heat exchanger (see Figure 7./30) or scraped surface heat exchangers can be used. The installation in Figure 7./32 shows that the product is surrounded by the heating and cooling medium and is transferred continuously. Depending on the application, stirrers and scrapers are used for good blending, constant removal of the product particles from the cylinder wall and transfer purposes. Residence time of the particles on the cylinder wall is 0.05–0.1 s, the total residence time can be controlled by the varidrive for the scraping elements (5–60 s) and the flow rates can reach 15,000 kg/h.

Stabilizers. For both the chemical and the thermal preservation, the addition of stabilizers is advantageous for achieving the following objectives:

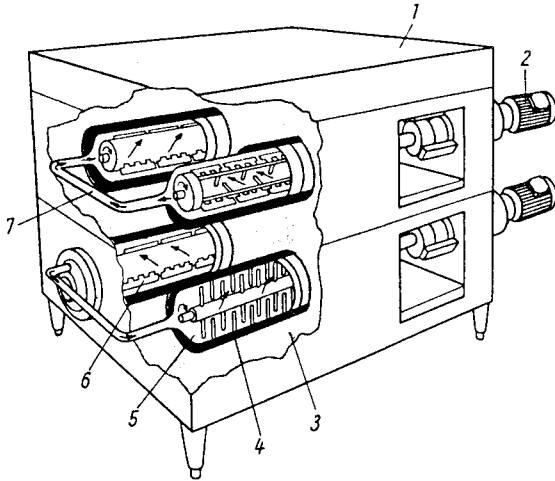


Figure 7./32
Scraped surface heat exchanger

(1) Housing (2) Drive motor for continuous mixer (3) Insulation (4) Heating and chilling media (5) Cylinder with product (6) Shaft with blades to scrape the product from the surface wall or stirrer blades for mixing of the product (7) Product pipeline

- a) Consistency improvement by viscosity increase
- b) Avoidance of whey separation by limiting syneresis
- c) Water binding and reduction of the water activity to $a_w < 0.96$ with simultaneous limitation of microbiological growth
- d) Avoidance of protein agglomeration during thermal treatment

Hydrocolloids including gelatin are very suitable as stabilizers, as shown in Section 5.2.2. Amounts are 0.1–0.5%. Addition can take place before the acidification step as well as directly into curd with the following possibilities:

- a) Dry sprinkling into the product at high turbulence
- b) For sweet products premixing with sugar in a ratio of 1:4, then blending with water or milk before final addition
- c) Predissolution in 5–10 times the amount of hot or cold water

Hydrocolloids, which coagulate casein in milk, can be added only after acidification. Hydrocolloids which are liquid only at elevated temperatures (e.g., agar-agar, gelatin) must be heated to liquefaction temperature and then blended with milk or water of the same temperature. Sometimes these taste-imparting additives already contain a stabilizer, which makes the addition easy to handle.

7.4.2. Quarg preparations, fresh cheese, quarg cream desserts

7.4.2.1. Quarg preparations

The basis for quarg preparations with different fat levels is a quarg with an initial low fat content and a dry matter content of 18–19%. According to the formula, pasteurized cream, vegetable oils (e.g., peanut or sunflower oil), fruit preparations (jams, marmalades, fruit purees), sugar, wine, liquors, chocolate coatings and dips, for spicy products salt ($K=1.8\%$), spices, herbs (e.g., dill, parsley, chives), cheese colorant are added.

Blending is done mostly batchwise for proper dosing of the additives, and to achieve a uniform distribution. For this purpose blending vessels with properly designed stirrers (see Figure 7./31) are used. A continuous operation is achieved by loading blending vessels in an alternate sequence, as shown in Figure 7./33. These blenders are equipped with computer-controlled weighing devices, so that the recipes can be maintained with a variance of $\pm 1\%$.

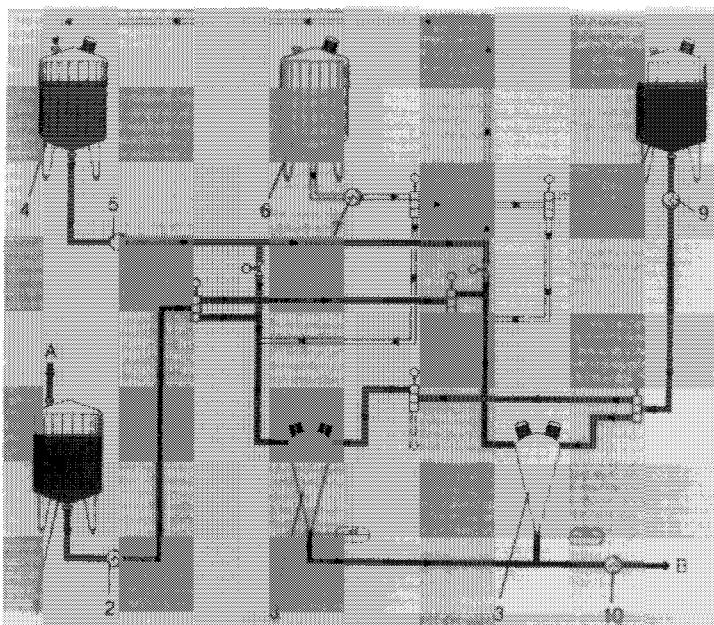


Figure 7./33 Continuously operating quarg blending installation

A Quarg from separator B Quarg to thermization

(1) Quarg silo (2) Displacement pump (3) Mixing vessel (4) Tank for stabilizer (5) Centrifugal pump (6) Cream tank (7) Displacement pump (8) Tank for fruit concentrate (9) Displacement pump (10) Displacement pump

7.4.2.2. Cream fresh cheese, double-cream fresh cheese

Cream fresh cheese is different from double-cream fresh cheese (as indicated by the name) in its fat level and its resulting dry matter and protein content. Cream fresh cheese with a 50% FiDM must have a dry matter content of $\geq 39\%$, double-cream fresh cheese, mostly with a FiDM of 70%, must have a dry matter content of $\geq 44\%$. In order to achieve these high fat contents in the finished product, part of the fat is incorporated into cheese milk; i.e., it is fat standardized. The balance of the fat is added in the form of cream or butter. A small percentage of this fat is transferred into whey during its manufacture.

Process. In the traditional separation process with filter bags or cloth, the initial dry matter content can be adjusted manually before adding the fat and other ingredients. This type of process yields a relatively firm product structure, which permits an easy forming and filling.

When separating with a separator, where a sufficiently large density difference between the materials to be separated are decisive for the separation effect, the basic differences between the cream fresh cheese and the double-cream fresh cheese become evident. For cream fresh cheese the fat content in the cheese milk is adjusted to 3–3.5%, resulting in a density of the protein-fat blend which is greater than that of the whey to be separated (about 1.0245 g/ml). For double-cream fresh cheese, the fat content is adjusted to 8–14%. This results in a density of the protein-fat blend of 0.93 g/ml, which is lower than that of whey. The consequence for the separation process is that the cream fresh cheese—like quarg—is ejected toward the bowl wall, and the whey is directed toward the center. For

double-cream fresh cheese, the material distribution is reversed due to the different density conditions. A cheese milk with 7% fat content has balanced density conditions, so that a centrifugal separation is nearly impossible. Due to these conditions, the separator bowls must be designed differently, as shown in Figures 7./34 and 7./35.

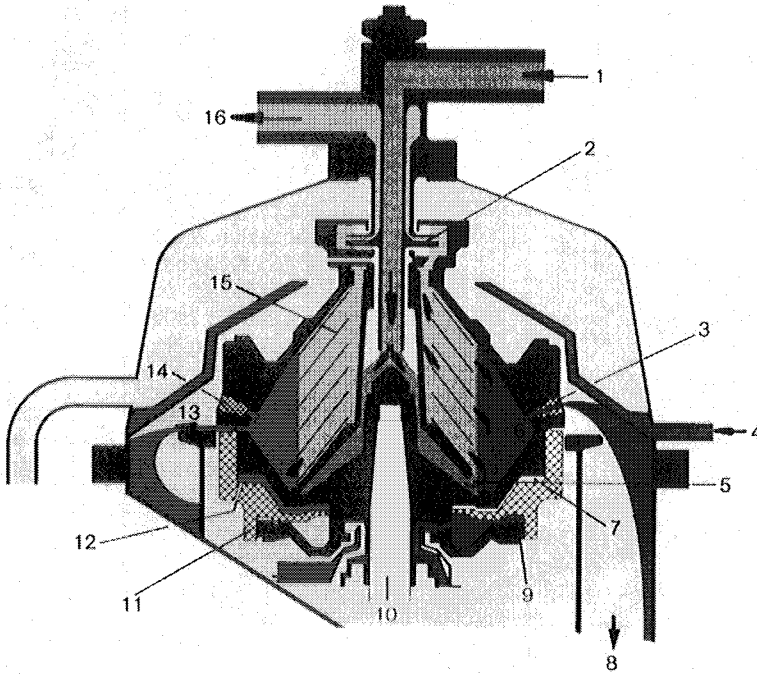


Figure 7./34 Separator bowl, type KNA for cream fresh cheese and quarg

(1) Inlet curd/ whey blend (2) Paring disk for whey (3) Nozzles for product discharge (4) Ice water inlet for lid cooling (5) Rising channels (6) Solid material chamber (7) Opening chamber (8) Cheese discharge (9) Closing chamber (10) Shaft (11) Piston rod (12) Discharge drill hole (13) Cheese discharge gap (14) Plug (15) Disk (16) Whey discharge

Process line/cream fresh cheese (Figure 7./36). Fat-standardized cheese milk from a tank (1) is preheated to 50–55 °C in a plate heat exchanger (3) and then homogenized in a homogenizer (4) at 175 bar. After cooling to the acidification and coagulation temperature of 25–27 °C, the milk is transferred into the coagulation tank (5), 1–1.5% of a starter culture is added, and 2 hours later coagulation enzymes (e.g., 0.5 ml of rennet with a strength of 1:10.000 per 100 l cheese milk) are added, so that a pH of 4.7–4.8 is obtained after 15–16 h and coagulation is achieved. After stirring of the gel, this curd/whey blend is transferred with a centrifugal pump (6) through a plate heat exchanger (7), is heated to 55–60 °C and reaches a reaction vessel (8), where it stays for 15 min while being stirred. This serves to firm up the developed protein structures and then to obtain the desired high dry matter levels during the separation process. In a plate heat exchanger (10), this blend is further heated to 80 °C to prolong the shelf life of the finished product and to denature the whey proteins [which is done during its residence time in the reaction tank (11)]. Thereafter separation takes place in a centrifuge (13), salt is added to the reception tank (15), and blending is done in tanks (19). Fresh cheese can then be hot-filled at 65–70 °C or can be cold-filled at 10–12 °C after passing through a cooler (21).

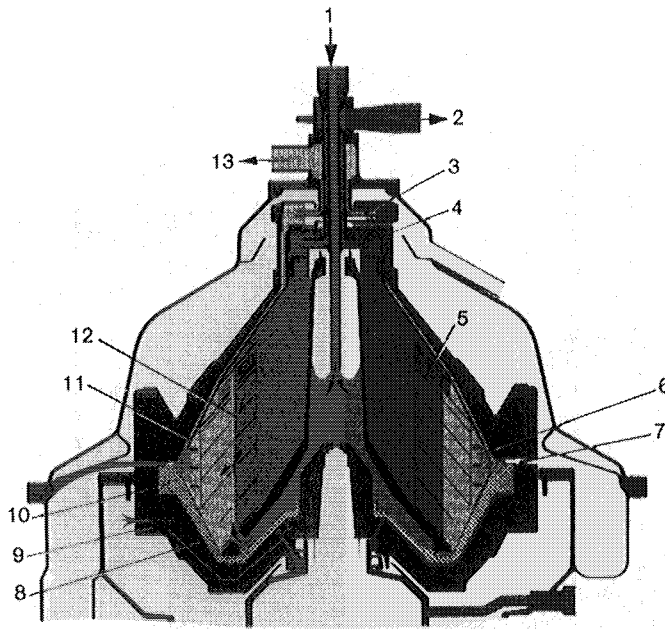


Figure 7./35 Separator bowl, type KSA for double-cream fresh cheese

(1) Inlet curd/whey blend (2) Cheese discharge (3) Paring disk for whey (4) Paring disk for cheese (5) Disk (6) Solid material chamber (7) Solid material discharge opening (8) Closing chamber (9) Piston valve (10) Piston rod (11) Separation disk (12) Rising channels (13) Whey discharge

Process line double-cream fresh cheese. Basically the same process line is used as for cream fresh cheese. However, the first heating operation including the reaction time is eliminated, so that the curd/whey blend is immediately heated to 80 °C, transferred straight into a reaction tank, and then separated in a special centrifuge (see Figure 7./35). Further processing is similar to that for cream fresh cheese.

7.4.2.3. Quarg cream desserts

These product are characterized by their grainy and foamy consistency. This is achieved by incorporating gas (e.g., nitrogen) or whipped cream into quarg or quarg preparations. This results in a volume increase of 25–30%.

For stabilization purposes, hydrocolloids are used at levels of 0.5–1.0% addition. The stabilized and refrigerated products (< 15 °C) are then foamed with mixing installations as shown in Figure 7./32. Blending times should not exceed 15 minutes and the foam structure should not be destroyed.

For a quarg cream dessert the following recipe is suggested:

Quarg, low fat	52%
Whipped cream 30 % fat, whipped	31%
Sugar	10%
Flavored sugar (e.g., vanilla, lemon)	1%
Drinking water for dissolving the hydrocolloids and the sugar	5%
Hydrocolloid	1%

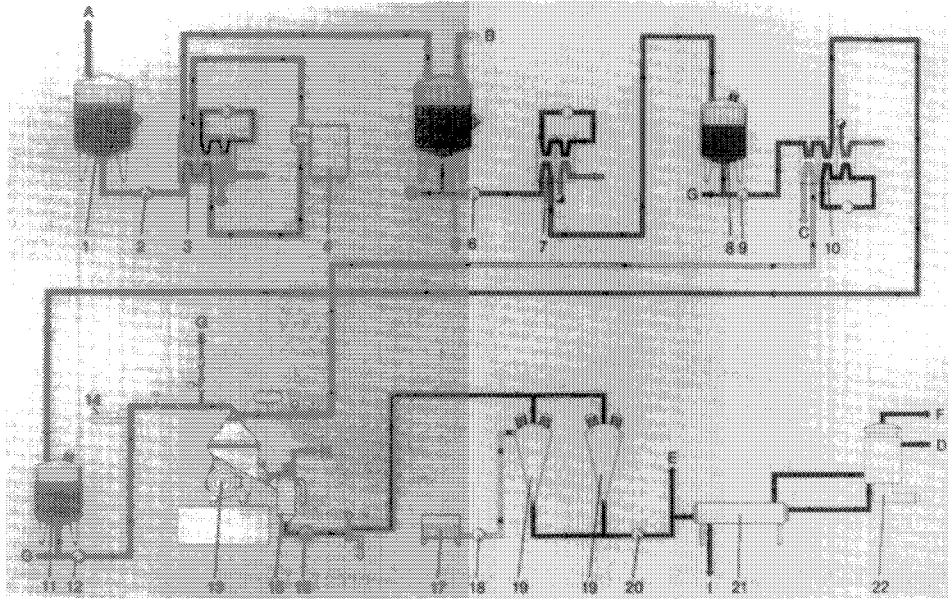


Figure 7./36 Process line for cream fresh cheese

A Pasteurized milk **B** Starter culture and coagulation enzyme **C** Whey discharge **D** Cooling medium—inlet **E** Fresh cheese for hot filling **F** Fresh cheese for cold filling **G** Water inlet **H** Salt addition **I** Cooling medium—return flow

(1) Milk tank (2) Centrifugal pump (3) Plate heat exchanger (4) Homogenizer (5) Coagulation tank (6) Centrifugal pump (7) Plate heat exchanger (8) Reaction vessel (9) Centrifugal pump (10) Plate heat exchanger (11) Reaction vessel (12) Displacement pump (13) Quarg separator (14) Flow control (15) Reception vessel (16) Displacement pump (17) Cream vessel (18) Displacement pump (19) Blending vessel (20) Displacement pump (21) Precooler (22) Scraped surface cooler

7.4.3. Layered cheese

Layered cheese is characterized by a firm consistency as well as colored and fat-varying layers of cheese mass. A yellow center layer, which becomes evident when cutting the cheese, should make the product more attractive to the consumer.

During manufacture, about one third of the cheese milk is colored slightly yellow and standardized to a higher fat content as the other two thirds of the cheese milk. Irrespective of these different fat contents, the finished product declaration is based on the average fat content. Fat standardization is always done in the cheese milk. Cream cannot be added without destroying the firm structure.

Coagulation temperature is 25 °C, the amount of rennet is slightly higher than for quarg, so that coagulation times is shortened by 3–4 hours. The relatively firm gel is then cut coarsely and is filled into molds with dimensions of 10x10 cm with a conical bottom. First is a layer of noncolored milk, then the colored layer and then again the noncolored milk. The finished layered cheese is packed individually in laminated aluminum foil or plastic cups. Individual packs have a net weight of 250 or 500 g. A process line with continuous coagulation is shown in Figure 7./37.

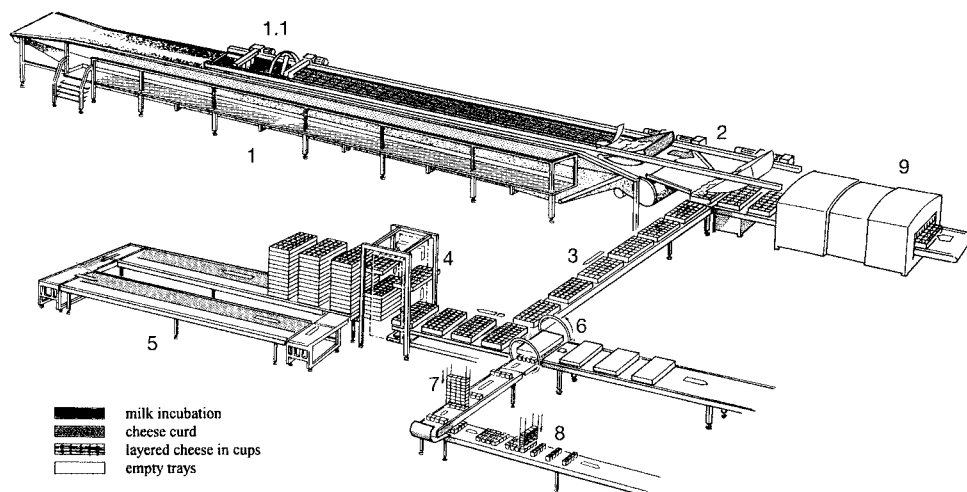


Figure 7./37 Process line for the manufacture of layered cheese

(1) Coagulator (1.1) Curd cutting device (2) Portioning chute (3) Mold transport (4) Stacking/ de-stacking (5) Drainage section (6) Individual turning (7) Packing (cup packing) (8) Lid closing (9) Cleaning installation

7.4.4. Buttermilk quarg

Buttermilk, which is a by-product of butter manufacture, is a highly nutritious acidified milk drink. The main reason is the fat globule membrane with its specific content of lecithin, which is transferred into the buttermilk. Buttermilk quarg has a higher lecithin content than standard quarg. As the market does not always absorb the produced buttermilk, the consequence is production of buttermilk quarg.

When butter is manufactured from sour cream, buttermilk is produced having a pH of <4.6, therefore an additional acidification for the manufacture of buttermilk quarg is not necessary. If butter is manufactured from sweet cream, it must be acidified before further processing.

Process. The acidified buttermilk is heated to 65–70 °C for microbiological stability, held for 40 s, cooled to a separation temperature of 42–45 °C and stored for 60 minutes in a tank with constant stirring. The purposes are deaeration and protein stabilization. The following centrifugation and all other processes are similar to those in the production of quarg.

Nonacidified buttermilk is also heat treated at 72 °C for 40 s, cooled to 28–30 °C and stored in an acidification and coagulation tank. After adding the starter culture and the coagulation enzymes, it is processed as in the manufacture of quarg.

7.4.5. Cottage cheese

This type of fresh cheese—also known as grainy cheese or more commonly as cottage cheese—is characterized by a soft grainy structure. It is obtained mainly by acid precipi-

tation of casein. Whey proteins are undesirable; therefore, pasteurization of the cheese milk is done with a short-time heat treatment.

Process. A flowsheet for the manufacture of cottage cheese is shown in Overview 7./10 and a process line with a continuous coagulation is shown in Figure 7./38. Specific production characteristics are cutting, stirring, and later washing of the curd (whey is already removed to a large extent). Cottage cheese is manufactured mostly as a low-fat or intermediate fat type and has the following composition:

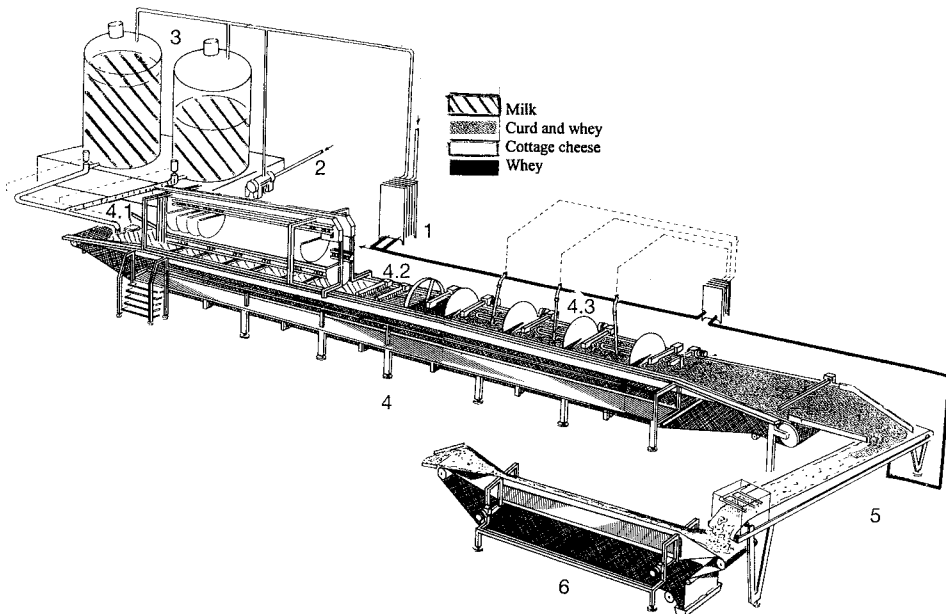


Figure 7./38 Process line for the manufacture of cottage cheese

(1) Plate heat exchanger (2) Starter culture dosing (3) Milk incubation (4) Coagulator (4.1) Milk flow control (4.2) Cutting station (4.3) Stirring installation with indirect preheating (5) Whey drainage belt with curd washing station (6) Pressing belt for dry matter control

Water	78.0%
Dry matter	22.0%
Protein	12.3%
Fat	4.3%
Fat in dry matter	20.0%
Lactose	3.3%
Energy	430.0 kJ
pH value	4.5–5.0

Appearance	grainy, dry
	fine curd diameter 4–5 mm
	medium curd diameter 6–7 mm
	coarse curd diameter 10–12 mm
Taste	neutral, clean
Shelf life (refrigerated)	2–4 weeks

Overview 7./10 Basic flowsheet for the manufacture of cottage cheese¹

Unit operation	Process and product parameter	
Skim milk		
Pasteurization	72 °C and 15 s holding time	
Cooling to incubation temperature		
Culture addition and incubation	Quantity 5% 1.01–5 % 0.25–1 % pH 4.8	time and temperature 32 °C, 5 h 22–32 °C, 5–12 h 22 °C, 12–16 h
Cutting of the acid gel		
Incallediate storage of curd	15–30 min	
Postheating and stirring	to 55–70 °C for 100–120 min	
Stirring	15–20 min at max. post-heating temperature	
Discharge of whey and washing	1. washing T_{water} 21–27 °C 2. washing T_{water} 10 °C 3. washing T_{water} 2–5 °C	
Fat standardization in dewatered quarg	Addition of 56 kg cream at 12% fat to 100 kg of quarg	
Filling and packing		

¹ Puhán, Z.: Sauermilchprodukte. Edited by Milchtechnische Institut der Eidgenössischen Hochschule Zürich, 1973.

7.4.6. Packaging of fresh cheese

- Fresh cheese must be packed immediately after its manufacture and must be cold stored.

Apart from the requirement for hygienically acceptable and light-, gas- and vapor-impermeable packing materials (plastic cups, aluminum laminate), the process depends on the required shelf life properties. For the filling of thermized products there are two options:

- a) Aseptic cold filling, where the packing material has been sterilized by a hydrogen peroxide treatment and/or UV treatment (2–5 cm distance to the lamp, time 2–3 s)
- b) Hot filling at temperatures > 65 °C with concurrent sterilization of the packing material

Additional protection against microbial spoilage is given by a headspace gassing with CO₂ when filling aseptically. At the same time, an additional perceptual benefit of “fresh taste” is achieved. For packing two systems are used:

- a) Installations for filling and packing of premanufactured cups and
- b) Installations with deep-drawing devices for the manufacture of cups and filling and closing devices.

For filling of the double-cream fresh cheese into laminated aluminum foil, machines are used as described for butter packing. Both machines for cup filling, described below, do not have the additional devices for aseptic filling and deaeration but can be used for hot filling.

Dosing and filling machine type PK (Figure 7./39). Cups are picked up from a magazine (3) and placed by suction devices into the cavities of a transport wheel (7). This wheel moves the cups to the printing station, where the minimum shelf life indication is printed on the bottom of the cup; they are then transferred further to a piston filling station (2).

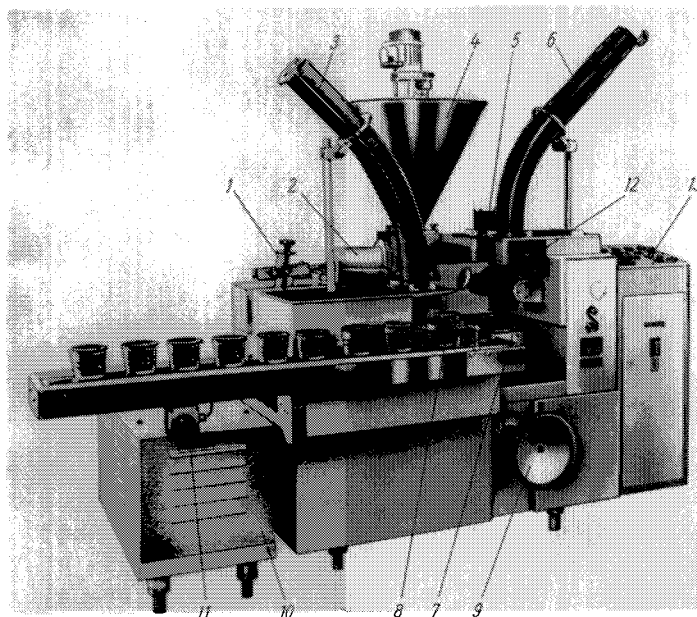


Figure 7./39 Dosing and packing machine, type PK

(1) Stroke adjustment for filling station (2) Piston dosing station (3) Cup magazine (4) Buffer vessel for product (5) Cover magazine (6) Lid magazine (7) Transport wheel (8) Conveyor belt (9) Wheel for manual operation (10) Vacuum pump (11) Safety switch (12) Suction device (13) Control panel)

Here the amount of product is pushed from the buffer vessel (4) into the cup by a piston (its stroke can be adjusted to vary the quantity). When using nonprinted covers, a preprinted sheet of plastic or wax paper is placed on the cup (by using a suction device), and another device takes a clear see-through cover from a magazine (6) and places it on the cup. The required vacuum is generated by a vacuum pump (10), placed besides the machine. The capacity for such a machine is up to 120 cups per minute.

Filling machine for deep-drawn cups, type BKT (scheme in Figure 7./40). A precoiled thermoplastic laminate is transferred to a deep-drawing station. Contact heating plates (1) heat the laminate to the forming temperature of about 200 °C, so that the cups can be shaped in the molds (2). The interchangeable mold is set for the column and the number of cups. Then the cups reach the filling station (3) sequentially, where the product is dosed, and the lids are sealed (4) onto the cups at a temperature of 140–180 °C. In the press (5), the cups or groups of cups are separated and are then transferred onward on a conveyor belt (6). Capacity of these machines is 2000–6000 cups per hour.

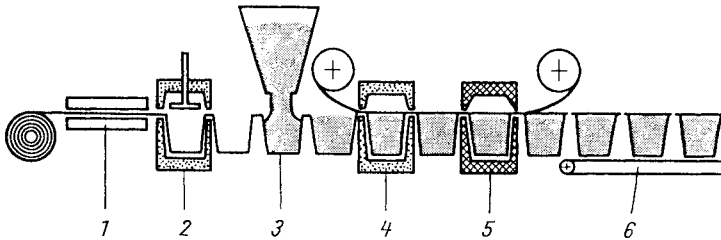


Figure 7./40 Scheme of a packing machine for deep-drawn cups

(1) Heating of the laminate (2) Shaping of the cups (3) Filling (4) Closing/sealing (5) Pressing (6) Transport of the cups

7.4.7. Quality evaluation

Basically the same criteria are applied as for rennet cheese (see 7.3.11). During the organoleptic evaluation, properties such as appearance, structure (structure and consistency), taste and flavor are evaluated. Requirements for the standard products are shown in Overview 7./11. For the evaluation of chemical-physical properties, fat, fat in dry matter, dry matter and water content of the nonfat cheese mass is determined.

Overview 7./11 Sensorial properties and characteristics of fresh cheese types

Type	Appearance	Structure	Taste and flavor
Quarg	Milky white to creamy yellow color	Dough uniformly smooth to paste-like	Light, clean milky sour
Layered cheese	Milky white to creamy yellow color	Cut surface is mat, layers should be visible in the interior, yellow layers must have a higher fat content than white layers, only a few curd holes in the dough, firm dough	
Cream fresh cheese	Milky white to slightly yellow color	No holes, pastelike and spreadable dough	Slightly acidic
Double-cream fresh cheese	Milky white to slightly yellow color	No holes, pastelike and spreadable dough	Slightly acidic

Regarding the microbiological aspects, good qualities should not have coliforms in 0.1 g, and the maximum level of 200 yeast and mold per g product should not be exceeded. The most important defects in fresh cheese and their reasons are shown below:

Fresh cheese defects and their reasons

Defect	Reason
“Yeast”, “old”	Improperly cleaned tools, filter cloth or bags loaded with yeast, bad starter cultures, improper cooling after manufacture
“Bitter”	Enzyme quantity and coagulation temperature too high, improper cooling
“Smeary”, “fermented”	Yeast contamination, improper cooling, too long storage
“Sour”	Too acidic at time of coagulation, whey discharge too slow

7.5. Cheese from sour milk quarg

Here we find products like sour milk quarg and cooking cheese; a similar type is herbal cheese.

- Sour milk cheese is a product manufactured from sour milk quarg by using approved additives; its surface is covered with a yellow smear and/or mold-ripened and is distributed at different degrees of ripeness. This results in the products such as Gelbkäse (yellow cheese) and Mold-ripened cheese.
- Cooked cheese is a product manufactured from sour milk quarg by adding approved additives and subjecting it to a heat treatment.

The production of sour milk cheese is mostly done in specialized plants (not in normal dairy plants), as the base material sour milk quarg, manufactured from milk in dairies, can be stored or transported over longer distances or times.

7.5.1. Sour milk quarg

Sour milk quarg is a semi-finished product and is manufactured from pasteurized skim milk which has to meet basically the same quality requirements as cheese milk. Protein coagulation is done exclusively by acid precipitation (see 7.3.4) in combination with heat but without enzymes. Lactic acid forming starter cultures are used, and their composition and applied temperatures result in two different acidification types, a cold acidification and a warm acidification. Some technological parameters are given in Overview 7./12.

Overview 7./12 Acidification profile for sour milk quarg

	Cold acidification	Warm acidification
Acidification temperature of milk	21–27 °C	40–42 °C
Starter culture addition	1–2 %	2–5%
Composition of starter culture	Mesophilic acidification culture (see also Overview 2./ 8)	Thermophilic acidification cultures as a blend of, e.g., <i>Lactobacillus delbrueckii</i> subsp. <i>bulgaricus</i> and <i>Streptococcus salivarius</i> subsp. <i>thermophilus</i>
Coagulation time	15–18 h	1.5–2.5 h

Production. In the traditional production method, milk is filled into vessels or tanks, after having been tempered to the acidification and coagulation temperature, and a starter culture is added. The acid gel is cut after coagulation into pieces of 10–20 cm so that a significant part of the whey can be drained. Then a slow but intensive curd treatment takes

place, i.e., stirring of the curd, until a grain the size of hazelnuts or walnuts has formed. Then a significant part of the whey is removed (which should have an SH of 22–24 and a pH of 4.6). Curd is then filled into filter bags or spread on filter cloth, and is pressed in special devices.

A continuous process can be obtained by using decanters, i.e., horizontal presses (see 7.9.1). In order to achieve sufficient separation, very firm protein agglomerate must be available during the curd treatment which can be subjected to high shear during the separation process.

Sour milk quarg should have a dry matter content of $\geq 32\%$ and an SH of 406–688 in dry matter. This corresponds to a titered SH of 140–210, which unfortunately is too imprecise to be used as a guideline due to the significant variations in the dry matter content. The SH value in the dry matter SH_{DM} is calculated from the dry matter content DM and the titered SH value $SH_{titered}$:

$$SH_{DM} = \frac{SH_{titered} \cdot 100}{DM}$$

Before filling, sour milk quarg is brought to a uniform grain size by passing it through mills or finishers, and it is then chilled to below 10 °C. Filling is done into paper bags with inserted plastic bags, plastic bags or containers.

- Plastic bags should be sealed without a headspace.

The filled quarg can stored for a short time in the dairy at temperatures < 8 °C, and for 2 months at temperatures ≤ 4 °C. A long-term storage is done in frozen form at -10 °C.

Quality evaluation. Organoleptic quality is evaluated on:

- Appearance white to slightly yellow
- Structure slightly brittle
- Flavor clean, slightly lactic acidic
- Taste clean, slightly lactic acidic

Chemical tests cover dry matter content, iron and copper content and the acid content. Iron and copper should be available only in traces, as otherwise discolorations would appear in the cheese. Further, the degree of ripeness is evaluated.

The most common defects in sour milk quarg and their reasons are:

Defect	Reasons
Too acidic	Stirring too late, pressing too late and too weak
Metallic	Water containing metallic ions, improper tools containing copper
Fruity	Yeast contamination due to unhygienic work procedures
Bitter	Degenerated starter culture, acid content too low in quarg
Chalky	Limited ripening due to butter and/or acetic acid

7.5.2. Sour milk cheese

The manufacturing process for sour milk cheese differ mostly in the surface treatment of the cheese. Mold-ripened cheese is treated with mold cultures (*Penicillium candidum*, *P. camemberti*) and yellow cheese with a red culture (*Brevibacterium linens*).

Ripening salts (0.5–1%) are added to sour milk quarg (key component sodium hydrogen carbonate NaHCO_3) for achieving an SH value of 110–130 and promote proteolysis, as well as 2–3% of salt and spices (mostly caraway seeds). This blend is then milled in special mills into a homogeneous mass and formed into small bars (cylindrical or bar form) having a net weight of 125 g, 100 g or 62.5 g. The cheese is placed on trays and is then subjected to a sweating process for 48–72 h at 20–25 °C at 90 % rel. humidity; water is removed and then the main ripening begins in the ripening rooms. Mold cheese is sprayed with a diluted culture. After a short ripening time, skin is formed by the yeast, a so-called fatty skin. This is an indication that yellow cheese must be surface-treated (i.e., brushing with a soft brush) with a brine containing a red culture. Ripening takes place at 10–16 °C and at 90–95 % rel. humidity. After 3–4 days a smear develops with the yellow cheese; for mold cheese a fungus patch develops.

- Proteolytic ripening of sour milk cheese progresses visibly with the acid denaturation from the exterior to the interior.

Cheese is ready for distribution when it has ripened up to 25% and when consumption ripeness has reached one third. Consumers often continue this ripening until the entire mass has been modified proteolytically, i.e., is “ripened through.”

7.5.3. Cooked cheese

Cooked cheese is manufactured from sour milk quarg, sometimes by adding normal quarg. The base raw material with an SH value of 150, is blended with 0.5% curing salts and is spread in a layer 10–15 cm high on trays and ripened for 4–6 days, until the mass appears to be fatty/tallowy. Then this cheese mass is milled, salt and spices are added and it is transferred into a stainless steel vessel (see the universal blender Figure 7./31) for heat treatment. For improving spreadability 10–15% water can be added and for increasing the fat content, cream, butter or butterfat can be incorporated. While stirring continuously, the mass is heated to 70–75 °C for 10–20 min until a syrup-like consistency is obtained. Then this mass is hot-filled into cups or aluminum laminate and cooled, resulting in the final consistency (which is spreadable).

Quality evaluation. Organoleptic properties of the individual types are shown in Overview 7./13. In a chemical test, sour milk cheese—which is manufactured mostly as a low-fat type—should have a minimum dry matter content of 32% and a salt content of 3.6%. Cooked cheese must comply with the fat grade requirements and the salt content should be 2.4%.

The most common defects in sour milk cheese and their reasons:

Defect	Reasons
Flowing cheese	Quarg too moist, contamination with proteolytic yeast
Gray-white coating	Yeast and mold contamination
Too firm dough	Quarg too dry, acid level too high, insufficient curing salt
Dark colored	Too high level of metallic ions in quarg
Green fungus	Contamination with cave molds

Overview 7./13 Organoleptic properties of sour milk and cooked cheese

Type	Appearance Exterior	Appearance Interior	Taste and flavor
Harzer, Mainzer	As a yellow cheese smooth surface with yellow to red-brown smear	White to slightly yellow, smooth and firm dough	Mild to spicy
Handkäse, Bauernhandkäse, Korbkäse, Stangenkäse, Spitzkäse	As yellow cheese like Harzer, as mold-ripened evenly covered with Camembert mold	As yellow cheese like Harzer, as mold-ripened cheese with white to slightly yellow color, smooth and firm dough	As yellow cheese like Harzer, as mold-ripened mild, flavorful to slightly spicy
Olmützer Quargel	Like Harzer	Dough firmer than Harzer	Spicy
Kochkäse	Dry matte surface	Green to yellow-brown dough, dough homogeneous, nearly spreadable, some holes	Clean, mild, spices are noticeable

7.6. Cheese with herbs

The basis for cheese with herbs is “Ziger” (which is whey-coagulated milk protein from pasteurized skim milk). For this purpose, milk is heated to 80 °C in a cheese maker, and 10–15% deproteinized acid whey (SH > 70) is added, and an acid curd forms after constant stirring at pH 4.65. Then whey is removed, and the protein is filled into filter bags or spread on a filter cloth in order to remove more whey and is then pressed after a 4–6 week ripening period at 20 °C. The fermentation process which takes place during this time, producing among others some butyric acid, imparts the typical flavor and taste of “Ziger.”

For preparing a herb cheese, Ziger is cut from the ripening boxes, is disintegrated and herbs are added (e.g., parsley). It is then well mixed and pressed into small cones. This cheese, which is stored very dry (<80 % relative humidity), has a very hard consistency and is normally grated before consumption (for seasoning purposes). Butter can be added to the grated herb cheese, and this product is commercialized as a cheese cream with herbs with a fat level of 50 or 60% FiDM.

7.7. Processed cheese**7.7.1. Terms and definitions**

The characteristics of this cheese are already in the name; i.e., in manufacturing the cheese is processed with heat and melts. For this, rennet cheese, mainly hard and semi-soft cheese, less soft cheese, is blended and made into a uniform mass by using melting salts.

- Processed cheeses are manufactured by using additives (mainly melting salts) and are subjected to a heat process.
- Processed cheese products are products made from processed cheese or from cheese and processed cheese. They are manufactured by adding milk products and/or other food ingredients (for flavoring purposes) in the same way as processed cheese.

- Cheese compositions are manufactured from two or more types of cheese, processed cheese, cheese preparations or processed cheese preparations.

The manufacturing process for processed cheese was developed by the Swiss Gerber and Stettler shortly after the turn of the century. The main purpose was to impart a shelf life to small hard and semisoft cheese for export purposes. During the last few years, a separate manufacturing trend has developed, which has improved the marketing potential. Key reasons are:

- a) Long shelf life due to the heat treatment and the hot filling
- b) Wide variety due to multitude of ingredients and composition
- c) Efficient utilization due to spreadable consistency and small portions
- d) Upgrading of defective rennet cheese products which limit its shelf life, but are still consumable

7.7.2. Technology

The technological process is divided into four parts:

- a) Selection, storage and preparation of the raw materials
- b) Blending of raw materials and additives
- c) Processing (melting process)
- d) Posttreatment and packing

For ergonomic reasons, installations for the manufacture of processed cheese follow the principle of gravity flow, as the dry blending ingredients are transported by chutes or tubes, and the hot highly viscous cheese mass flows by gravity from the processing vessels to posttreatment or packing. Another principle of manufacturing is based on a single-floor flow, where processing activities take place on raised platforms. Figure 7./41 shows the basic flow of a gravity flow manufacture.

7.7.2. Raw materials

- Raw materials are ripened rennet cheese and sometimes other types of cheese which can be utilized for processed cheese.

Selection. For processing (melting) basically all types of rennet cheese are suitable, and to a certain extent quarg and sour milk cheese can be added. The best melting characteristics are shown by hard and semisoft cheese types, among them especially Chester due to the specifically “fibrous” structure of the cheese mass.

- The basis for good processed cheese quality is good quality of the raw materials.

The types of cheese that can be processed include those which cannot be sold any more due to damage or rind defects as well as small pieces which result from the portioning process. Some “green” products are also used. This is basically cheese whose ripening process has just begun or is not yet completed and which has been sold for processing. The suitability of a cheese for processing is mainly given by the water content or dry matter content, pH value, organoleptic properties and degree of ripening.

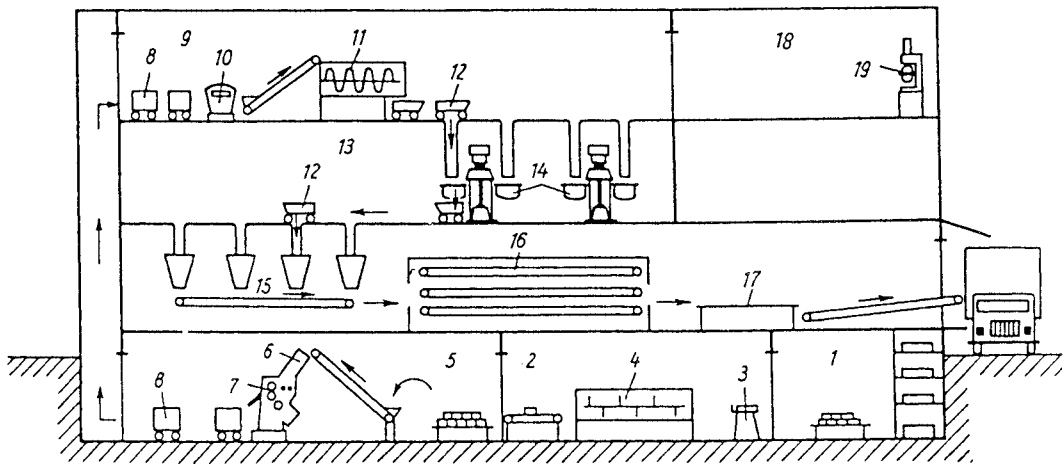


Figure 7./41 Basic layout for manufacture of processed cheese (gravity flow)

(1) Storage room (2) cleaning room for raw cheese (3) Deskinning of cheese (4) Washing drum (5) Premilling and grating (6) Grating (7) Triple drum installation (8) Transport trolley (9) Blending room (10) Balance (11) Double-drum blender (12) Transport trolley with bottom discharge (13) Melting room (14) Melting machines (15) filling machine (16) Cooling tunnel (17) Packing and distribution (18) Laboratory (19) Melting pan for samples

Raw material control, storage and preparation. Raw materials are first subjected to an organoleptic and chemical quality check, and the quantity is determined. Analytical data are the basis for the blending of batches.

Until processing, the individual cheese types and qualities are stored separately at temperatures of 10–14 °C and a relative humidity of 85–95 % and are handled carefully. Some types such as Chester are stored at 0–5 °C. Ripened cheese can also be stored at below –18 °C.

The preparation of cheese with a firm skin (rind) consists of a softening process in a water bath, which ensures that the skin will melt completely at a later stage. Further, the surface of the cheese is cleaned with brushes and warm water, and some skin defects are removed. Waxy rinds or plastic coatings are removed. Sometimes a complete deskinning is done, which results in product losses. After the ripening process are a milling process and blending into melt batches.

- If processed cheese is labeled after a specific type of cheese, at least 75% of this type must be in the product.

7.7.2.2. Blending and additives

The degree of ripening of the raw material is very important when preparing the processing batches, as it controls the melting process to a large extent. Influences are shown in Overview 7./14.

The degree of ripening can be expressed in terms of relative casein content (ratio of nondecomposed protein to total protein) according to Schulz and Mrowetz. The relative casein content for firm processed cheese should not be less than 70% and for spreadable processed cheese it should not be less than 50% in the raw material blend. Normally, cheeses of different ages are blended in order to obtain the desired quality.

Overview 7./14 Influence of ripening degree on the melting process

Factor	Advantages	Disadvantages
Young cheese (short ripening)	Good dispersion, permitting a good emulsion of the added butterfat; high water binding capacity; state of emulsion can be easily maintained during melting of the product	Long intensive treatment for protein digestion required; if melting time too short, then a high-viscosity, rubber-like dough can form; tendency for a plain, sour taste; adheres easily to filling machine; pH value must be corrected; slow dispersion
Old cheese (long ripening)	Rapid dispersion, pronounced to spicy taste	Soft, sponge-like melting product with a mat appearance; has a tendency for "oiling"; low water binding capacity; if water binding capacity is exhausted, then "overcreaming," i.e., postformation of a short, wet, solid dough with a short shelf life occurs

Utilization of reprocessed material is favorable for the finished product. This material serves as an additive for other processed cheeses, accelerates dispersion and "shortens" the dough structure, resulting in a creamy, spreadable processed cheese. Reprocessed cheese can also be manufactured directly from the milk as a so-called melt pack. For this purpose, rennet cheese curd is blended with a polyphosphate, resulting in a taste-neutral rennet cheese product with a relative casein content of 90–100%.

Another "reprocessed" product is the "base cheese mass," and it is manufactured by ultrafiltration of milk, evaporation of concentrate, followed by acidification and enzymatic coagulation. This mass is used unripened for melting by blending it with other normal raw materials.

Calculation of the batches. When considering the type and degree of ripening, analytical data for dry matter and fat in dry matter of the raw material must be known in order to calculate the production batches. The following sequence is possible:

- a) Fixing the quantities (by determination and/or calculation for dry matter, fat) in kg and % and addition of the amounts for dry matter and fat quantity
- b) Calculation of the theoretical fat content in dry matter according to

$$FiDM = \frac{m_f \cdot 100\%}{m_{DM}}$$

- c) Comparison of the theoretical $FiDM$ with the targeted one and eventual correction with cream, butter, low-fat or nonfat dry matter
- d) Calculation of yield Y according to

$$Y = \frac{m_{DM} \cdot 100\%}{DM_T}$$

- e) Calculation of the water to be added minus the water from the ingredients. Further, the amount of condensate (from direct heating) must be deducted. This value must be determined by trials considering steam pressure, water content of the steam, temperature, time of heating and moisture content of the product.

$FiDM$ fat in dry matter
 m_f fat quantity in kg

m_{DM}	dry matter in kg
DM	dry matter in %
DM_T	target dry matter in %

When preparing batches, the calculated $FiDM$ and the dry matter content should be selected slightly higher than the minimum requirement for each type in order to have a safety margin. Prepared batches are then disintegrated and grated in mills with attached grating devices (Figure 7.42). The three drums of the mill, made of porphyry, granite or stainless steel with a smooth surface, counterrotate at variable speeds.

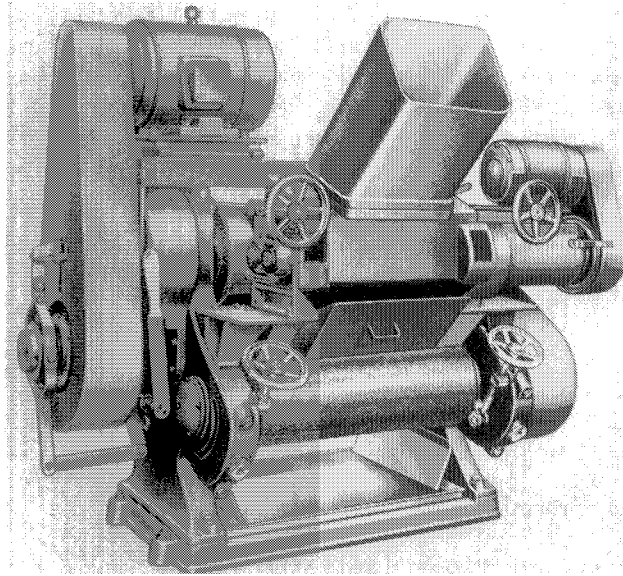


Figure 7./42 Mill with grating device for the disintegration of raw materials

Additives. Apart from technologically indispensable melting salts, other ingredients are added, such as acids (tartaric or citric acid) for pH control, salt (can be replaced by calcium chloride), cheese colors, water and other foods, spices and stabilizers for the heat treatment as well as fresh cheese (see 7.4.1.6).

Melting salts. Basically two groups of melting salts are used, mostly in the form of blends. If these salts are blended, then the maximum values for the groups must be respected.

- Citrates (sodium citrate, potassium citrate, calcium citrate) or lactate (sodium lactate, calcium lactate) up to a max. of 4 % of the cheese mass
- Phosphates (sodium, potassium and calcium ortho-phosphates, sodium- and potassium di-phosphate, sodium- and potassium tri-phosphate, sodium and potassium polyphosphate) up to a maximum of 2 % of the finished product and calculated as P_2O_5 .

Melting salts (acting as electrolytes) promote the formation of casein compounds, resulting in emulsifying and water binding properties. During the melting process they result in good dispersion of the ingredients and in a stable processed cheese emulsion. At the same time, separation of the main ingredients protein, fat and water is avoided when

heat is added to the melting cheese. Further melting salts adjust and optimize the pH. At too low a pH, the cheese mass is dissolved too slowly and disperses, and a processed cheese with short and brittle structure develops. When the optimal pH is exceeded, rapid melt-down occurs, with concurrent “overcreaming,” and a pudding-like spongy mass develops, which can be filled only with great difficulties. Optimal pH values are shown in Overview 7./16.

Addition of citrates results in a firm cheese with a long hydrated dough structure. Phosphates show good dispersion, so the hydration processes take place very rapidly and uniformly and a homogeneous and spreadable dough structure develops. The salt blends are designed for specific effects and product characteristics.

Addition of other food ingredients. These include butter, butterfat, cream, lactose, whey paste, whey cream, whey powder, spices (paprika, pepper, caraway seeds and others), meat and meat products (maximum 10% in the finished product), e.g. ham and salami, cocoa products, saccharose and wine. Addition of vegetable fats is also possible, increasing the nutritional value of processed cheese. Salt serves in taste refinement, cheese colorant for fine-tuning of color.

The prescribed water content is achieved by adding the necessary amount of water, based on the FiDM. The fat level is adjusted by adding butter or cream.

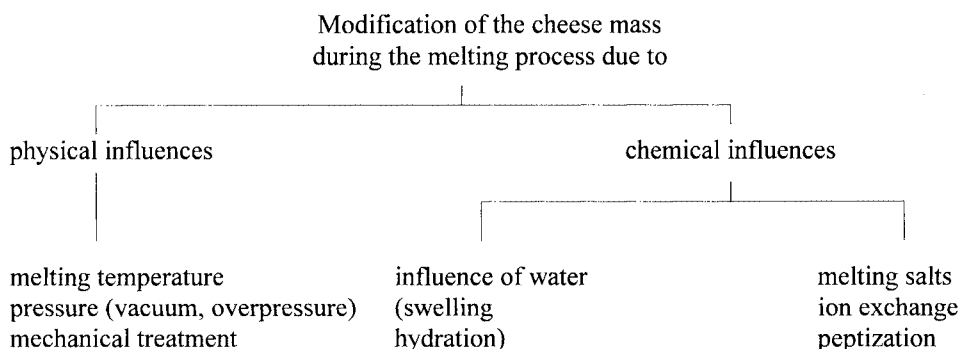
Incorporation of additives takes place shortly before the batches are put into the melting vessels, mostly directly into the vessel. In larger installations, additives are blended with raw materials in premix installations which can contain up to 1 ton of product thus creating a premix for 10–20 batches of processed cheese having a homogeneous composition. Volatile and heat-sensitive additives are added at the end of the melting process and are stirred for only 1–2 minutes.

7.7.2.3. Melting process

- The melting process is an operation, in which heat, mechanical treatment and effect of melting salts transform the disintegrated raw material together with the other additives into a homogeneous mass.

The characteristic activities during the melting process are shown in Overview 7./15.

Overview 7./15 Chemical-physical activities during the melting process



The typical structure of cheese—formed during the enzymatic ripening to form a calcium-paracaseinate network and firmed up, during the ripening—must be broken up. Small dispersible particles form and must be transformed during the melting process into

a stable emulsion. Disintegration in a milling and grating unit continues in the melting pan on adding heat and continuing stirring. Due to the heat, the particles contract (releasing fat and water) and the mass is destabilized. Melting salts reverse this phase separation, as they promote the exclusion of proteins and have a peptizing effect. Simultaneously there is an ion exchange between the calcium paracaseinate and the melting salts so that the melting salts absorb some calcium ions and discharge some sodium ions to the casein, thus forming sodium paracaseinate. The resulting change in the electric charge results in a reduction of the surface tension between water and protein and a greater formation of hydrating spheres on the surface of the particles.

A peptized sodium paracaseinate is much more dispersible, and a good colloidal distribution in the sol state is achieved. Together with the melting salts and the amino acids—which have been released during the ripening and melting of the cheese—it contributes to keeping the fat in an emulsified state or reemulsifying it. Ionization of the fat particles then results in a reduction of the surface tension, in this case between fat and water, thus stabilizing the state of the emulsion.

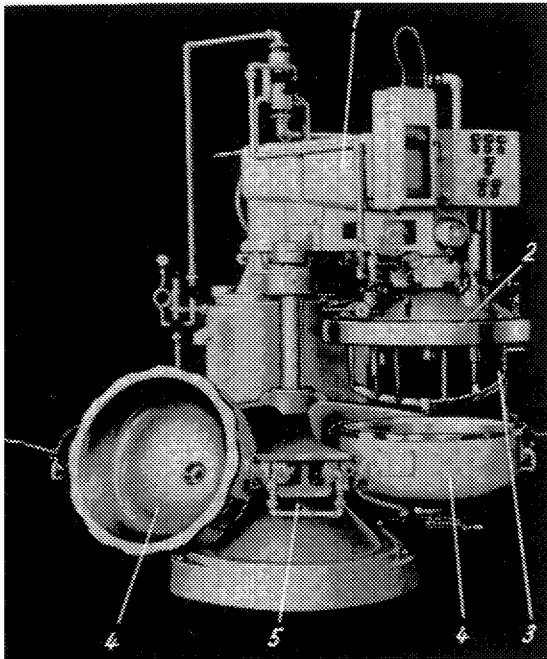


Figure 7./43

Large-scale cheese melting vessel, type Ps 200, suitable for heating up to 140 °C, corresponding to a saturated steam pressure of 4 bar

(1) Drive, control panel, temperature recorder and timer (2) Heated cover with thermometer and pressure gauge (3) Stirrer with variable speed (4) Melting vessel two-axial movement (5) Steam inlet

Conversion of the viscoelastic dough of the raw cheese into the typical short structure of the processed cheese during the melting is called “creaming.” It is caused by the hydration of proteins, which is another particle disintegration, and results in structural modifications. The hydration effect happens both in parallel during and after the dispersion but only at melting temperatures. This process is interrupted by cutting off heat or by cooling. Determining the exact time for this interruption is very important, especially when the hydration potential of the proteins is not yet fully exhausted. Otherwise an “overcreaming” can occur. The point of interruption is determined by trial and error.

Further, we observe water absorption by the melting mass, where the balance of the added water is bound. This results in a volume, mass and viscosity increase. As swelling is an exothermic reaction, this effect takes place mostly during the cooling phase of the cheese mass.

- Optimal adsorption is the basis for good consistency, spreadability as well as a homogeneous and smooth dough structure of the finished product.

Melting process. A prepared and pretreated batch of raw materials is transferred in trolleys to the melting machine or is conveyed via chutes and funnels. Normally batch-type melting machines are used; continuously operating machines are rare (Figure 7./32).

The melting machine in Figure 7./43 has two stainless steel tiltable pans equipped for heating, which can be raised and lowered hydraulically. Once a pan has been loaded with the raw materials and additives (net volume 10–100 l depending on the machine type, loading level 75–85%), the vessel is closed hydraulically by a lid (can also be heated). A stirring device is attached to the cover and can work at various speeds and provide good blending and uniform heating. In order to raise the product mass quickly to melting temperature, sometimes steam is injected directly into the vessel (besides using the normal indirect heating system; however, the steam needs to have a culinary quality).

The major control parameters are steam pressure, pressure and temperature inside the vessel, as well as cooling water pressure and temperature; all data can be measured by sensors, recorded and used for automatic process control.

- The melting process is finished when a uniform, smooth and homogeneous mass has developed. With firm cheese, the mass should flow off the stirrers in long strips, for spreadable cheese it should flow in very short strips

After opening the lid, the mass is discharged from the melting vessel into special trolleys having a bottom discharge device or flows into tubes (for a gravity-based layout). The melting vessels are operated in an alternate sequence; i.e., in one vessel the mass is melted, while the other vessel discharges and reloading takes place. The capacity of these vessels is 450 kg/h. The key parameters are shown in Overview 7./16.

Overview 7./16 Key parameters of the melting process

Parameter	Value, extent	Remark
Melting temperature	85– 95 °C (under atmospheric pressure and vacuum) 105–120 °C (under overpressure)	For raw materials with a high lactose content, temperatures are ≤ 90 °C to avoid a browning reaction (Maillard reaction); for rapidly dispersible raw material < 85 °C in order to pass quickly through the critical point of 65 °C (fat separation)
Melting time	4–8 min for firm cheese 7–15 min for spreadable cheese	
Speed	60–140 RPM	
pH value	5.4–5.6 5.6–5.9	Three speeds or variable
Vacuum in the melting vessel	0.33–0.60 bar	For firm cheese For spreadable cheese
Overpressure in melting vessel	1.2–2.0 bar	Vacuum results in a gentle melting, but results in a flavor reduction the higher melting temperature result in a better inactivation (except for Clostridia spores) and a nearly sterile product which has a long shelf life if filled aseptically. Before opening of the vessel temperature reduction to < 100 °C

Subject to the raw material and the desired quality of the processed cheese the following relationships are to be observed:

Firm processed cheese	gentle treatment in the melting vessel relatively high melting temperatures, short melting times, slow stirring melting salts which do not favor the “creaming” younger, slowly dispersing raw material no or low level of reprocessed material
Spreadable processed cheese	intensive treatment in melting vessel high melting temperatures, longer melting times, rapid stirring strong and dispersing melting salts higher level of reprocessed material medium to old raw material water addition in two or three stages

7.7.2.4. Posttreatment

Posttreatment covers the operations of cooling and packing as well as sometimes homogenization (this is done only in cases, in which a special homogeneous structure must be achieved, which follows the melting process).

Immediately after melting, the hot cheese mass is brought to the filling machines and filled rapidly. Rapid filling and ensuing cooling are interrupted by a so-called post-melting which prevents the overcreaming phenomenon.

- Spreadable processed cheese is shock cooled; firm cheese is cooled more slowly.

For cooling, the closed packs are conveyed through a cooling tunnel, where they are brought within 30–60 min to a temperature of 25–35 °C. If no cooling tunnel is available, the transport packs are placed on trays in cold rooms to achieve a sufficiently rapid cooling effect. Processed cheese can also be filled into casings and is then smoked.

Sliced processed cheese. Another form of portioning of processed cheese is slicing. For this purpose the hot cheese mass is spread onto a cooled steel conveyor belt, forming a film several millimeters high with a firm consistency. This cheese mass is then cut into slices with the desired dimensions, and the slices are placed on top of each other (in most cases separated by a piece of paper or another packing material) and packed. Slices of different types of processed cheese can be combined in a sales pack.

7.7.3. Quality evaluation

For the organoleptic evaluation the same principles are applied as for rennet cheese (see 7.3.11.). Most of the characteristics and properties are shown in Overview 7./17. For the chemical-physical evaluation fat, fat in dry matter and dry matter content are determined. The required minimum levels for dry matter are shown in Overview 7./18. The major defects and their reasons are discussed below.

Overview 7./17 Organoleptic properties and characteristics of processed cheese and processed cheese products

Type	Exterior	Interior a) Structure b) color c) surface	Flavor	Taste
Processed cheese firm	Smooth, shiny, closed surface	a) Firm plastified dough, visible additives well distributed b) According to used raw material and/or additives	Clean, close to typical character of the original cheese, additives pleasantly pronounced	Clean, close to typical character of the original cheese, additives pleasantly pronounced
Processed cheese preparations, firm	Few holes, edges slightly tapered	c) Smooth, closed, some tiny holes possible		
Processed cheese spreadable		a) Spreadable, matte, visible additives well distributed		
Processed cheese preparation spreadable		b) According to raw material and/or additives c) Smooth, closed, some tiny holes possible		

Defects in processed cheese and their reasons:

	Defect	Reason
Exterior	Mold and patch formation	Defective filling, storage rooms too humid
Interior	Too firm, brittle	Raw material pH too high; dry matter of processed cheese too high; cooling too slow
Taste and flavor	Sandy	Crystallization of the melting salts
	Gluey—plain	Too high percentage of fresh, non-ripened raw material
	Spicy, old	Too high percentage of old raw material

Overview 7./18 Minimum dry matter content of processed cheese and processed cheese preparations

Fat level	Processed cheese spreadable and preparations [% dry matter]	Processed cheese firm [% dry matter]	Processed cheese from hard cheese in individual slices (m ≥ 1000 g) [% dry matter]
Double cream	47	52	57
Cream	45	50	55
Full fat	43	48	53
Fat	41	46	51
Fat reduced	35	42	47
Semifat	33	38	43
Low fat	31	36	41
Nonfat	29	34	39

7.8. Packaging of cheese

Before commercial distribution from the manufacturing plant, the cheese must be packed, meeting the following requirements:

- a) Create transport suitability and protect against outside influences (dirt, dust, temperature variations).
- b) No reaction between packing material and product, i.e. no influence on flavor, taste and appearance of cheese.
- c) For rennet cheese, ripening must continue inside the pack, for processed cheese the pack must be airtight
- d) Pack must carry appropriate labeling

In cheese packaging we distinguish between the outer surrounding (sales pack) and the transport pack (outer packing)—see also Section 5.3.1. In most cases, the transport pack is designed in such a way that it fits onto a standardized pallet.

Special packing is one of the modes, especially when the cheese is covered with a coating (paraffin, plastic) during ripening or shortly before distribution; this includes pre-portioning, i.e., slicing and/or portioning.

7.8.1. Packaging material

In most cases, many different packaging materials are combined and utilized; key parameters are the type of product (cheese) and the means of packing, e.g., outer pack, transport pack. Major packing materials are shown in Overview 7./19

Overview 7./19 The most common types of packing for cheese

	Transport pack	Wrapping or sales pack
Hard cheese	Boxes and frames of wood/ plywood, cardboard boxes	Special laminates, waxed or coated, paraffin or plastic coating, smearproof paper
Semisoft cheese	Wooden boxes or frames with alu-coated laminate, wax paper, cardboard boxes	Packed individually into smearproof paper, laminated aluminum foil or plastic foil, compound or shrink-wrap laminate
Soft cheese	Wooden boxes, transport boxes made from cardboard	Packed individually into laminated aluminum or plastic foil, placed in wooden or cardboard boxes
Fresh cheese	Wooden boxes, cardboard boxes or boxes made from corrugated paper, plastic containers or pails	Plastic cups for quarg and layered cheese, cream and double cream cheese in laminated foil, placed clear plastic bags
Sour milk cheese	Wooden boxes, cardboard boxes	Cellophane, smearproof paper or laminated foil
Processed cheese	Cardboard boxes	Aluminum foil, lacquered and hot-seal capable, plastic laminate or tubes, plastic cups or tube
Cooked cheese, herbal cheese	Wooden boxes, cardboard boxes	Aluminum foil, plastic cups

7.8.2. Packaging technology

The simplest form of packing is the manual wrapping; i.e., each cheese is manually wrapped, and is then placed into the transport pack. This technology is justified for larger

types of cheese (hard and semisoft cheese), but only in cases of low product quantities. For larger capacities, packing machines or complete packing lines are necessary. This is valid for all types of cheese.

Figure 7./44 shows a filling and packing machine for processed cheese, in which the cheese is formed initially and then wrapped into the packing material. Machines based on the same principles are used for packing fresh cheese, if it is not packed into preformed or deep-drawn cups (Figure 7./39)

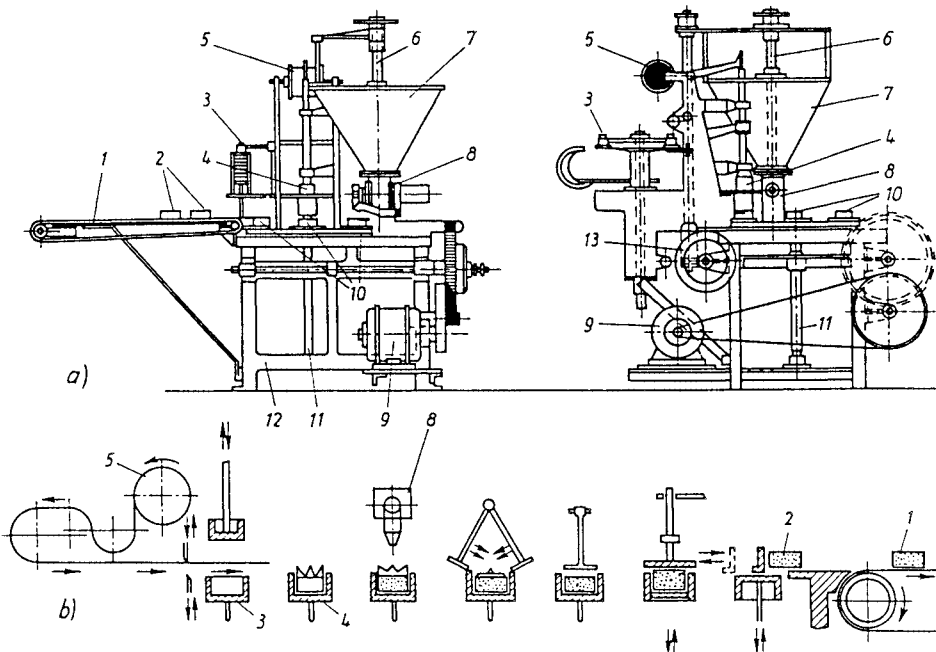


Figure 7./44 Machine for filling and packing of processed cheese

a) Total view b) Working principle

(1) Discharge conveyor belt (2) Cheese pack (3) Insertion and labeling station (4) Embossing station (5) Transport of packing material (6) Shaft (7) Filling funnel (8) Dosing device (9) Drive (10) Forming table (11) Shaft (12) Frame (13) Wheel for speed adjustment

For small semisoft cheese and soft cheese, which are packed and sold mostly in an individualized way different types of machines are utilized, which can have devices for automatic weighing and printing of weight and shelf life. Additional devices exist for placing the wrapped cheese into the sales packs (boxes).

- The basis for smooth packing is uniform cheese shapes and dimensions.

The operating principle of the machine shown in Figure 7./45 for packing soft cheese is that the cheese is placed manually or by a specific device on a conveyor belt and transported to the wrapping station. Packing material, having all the necessary marking, is transferred to the wrapping station, and a piston moves the cheese into place for wrapping. Wrapped cheese leaves the machine via a discharge chute to packing for transportation (into cans or cardboard boxes).

Hard and semisoft cheese can be packed by machines working on the same principles. Before selling, the packing material must be removed, as cheese is normally sold on a weight basis and not a piece basis.

Prepackaging/Portioning. Large cheese must be cut before being placed in the refrigerated sales cabinets, so that they can be offered in a portioned manner. For this the cheese is cut up into slices by cutting devices (Figure 7./46) and then packed accordingly.

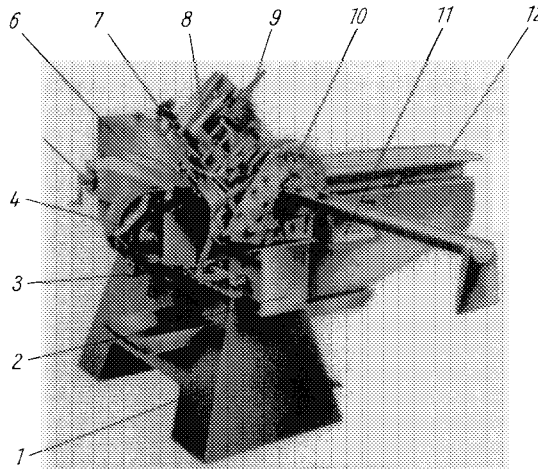


Figure 7./45 Packing machine for soft cheese type ALPMA U-63
 (1) Frame (2) Housing (3) Laminate transport (4) Gearbox (5) Gear (6) Drive (7) Device support (8) Laminate transport device (9) Perforation device (10) Control shaft (11) Control panel (12) Inlet

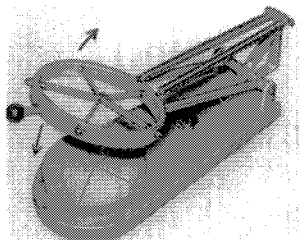


Figure 7./46 Small cheese pie section device

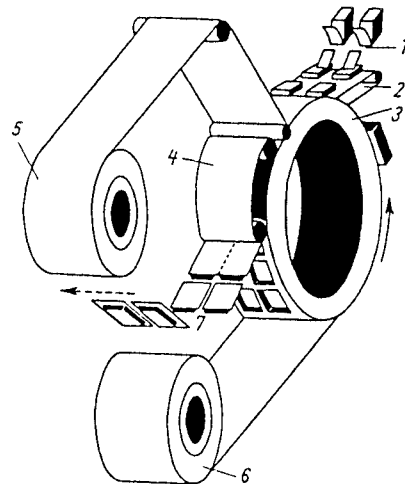


Figure 7.47 Working principle for the cheese slice packing machine, type FILUVID
 (1) Cutting station (2) Sequencing device (3) Packing machine (4) Vacuum station (5) Cover packing material (6) Packing material bottom laminate (7) Cutting device for packs

Figure 7./47 shows the working principle of a machine for packing cheese slices. Hard or semisoft cheese is precut into slices, which are then placed on top of each other and packed into laminate. In order to avoid sticking to each other, the slices are separated by a plastic sheet or smear-proof paper or each slice is sprayed with a food-grade oil.

Before sealing, the packs are submitted to a vacuum, which removes the oxygen needed by the microorganisms to grow, or air is displaced by the injection of an inert gas (CO₂, N₂ or blends of these gases). Portioned cheese slices are packed in the same way.

In the working scheme (Figure 7./47) of the slice packing machine (Figure 7./48) cheese is placed either in a cubed form or in large slices into the cutting station (1) and is then cut with a rotating knife into slices of different thickness or weights (as a function of the speed). Slices are placed on a conveyor belt (2) in the form of a stack or in an array and transferred to the molds of the bottom forms (6) of the packing station (3). A top laminate is applied, so that both laminates can be sealed airtight except for a small opening for vacuuming. In the vacuum station, air is completely removed and it is finally sealed. The double lane packages passes through a cutting station, where the packs are individualized and they are transferred further. The machine can also have a device for gassing.

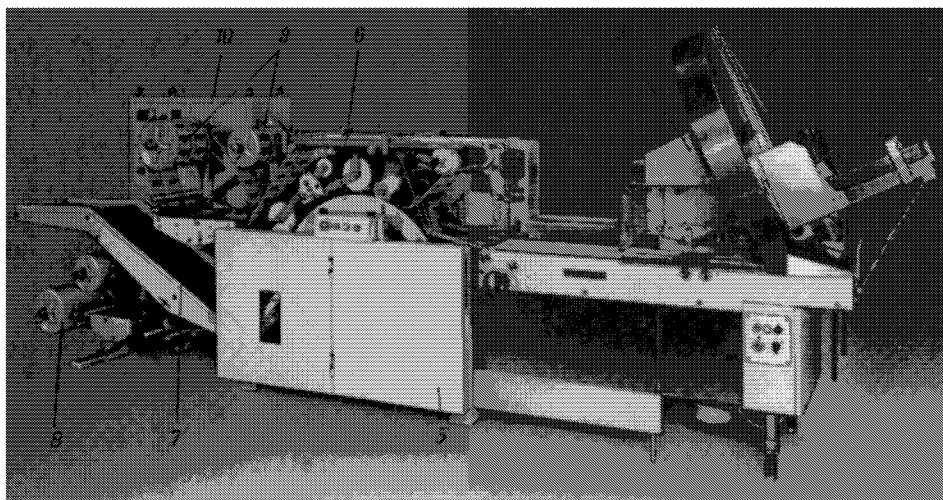


Figure 7./48 Slice packing machine type FILUVID; mold width 120 mm, mold length 120, 140, 158, 179 or 207 mm, mold depth 15–55 mm adjustable; content 1, 2, 3, 4, 5, 6, 8, 10 slices adjustable; slice thickness 2–10 mm adjustable, array distance 5–20 mm, variable; capacity maximum 60 packs per minimum depending on length; electrical connection 11 kW, compressed air 1.2 m³/h at 6.3 bar; air ejection 200–350 m³/h at 1.0 bar

(1) Product placement (2) Cutting station (3) Transfer station (4) Array device (5) Packing machine (6) Vacuum station (7) Discharge (8) Laminate for bottom tray (9) Laminate for top (10) Control panel, electrical connection

7.8.3. Paraffination, laminate ripening

Cheese (mostly semisoft cheese, less hard cheese) which has ripened and is ready for distribution is coated with a blend of paraffin wax or other coatings (polyacryl acidic es-

ter, acetoglycerides, PVC and others) or is placed into plastic bags, which has the following effects:

- a) Reduction of ripening losses
- b) Avoidance of skin defects due to microorganisms and others (e.g., mites)
- c) Reduced skin formation by moisture loss
- d) Reduced labor requirements by elimination of cheese handling during ripening
- e) No skin losses during prepackaging or processing into processed cheese

Paraffination. Ripened cheese with a dry surface is immersed into a liquid coating (110–150 °C), which contains mostly red or yellow colorants, and the entire surface is coated. For some cheese types like Chester, Edam or Gouda, a so-called early paraffination can be done; i.e., cheese is treated after salting and drying, latest 10–12 days thereafter. A well dried surface is very important, to avoid brittleness of the coating and later mold formation beneath this coating. The operation of such a paraffination machine is shown in Figure 7./49.

Laminate ripening. Here cheese is wrapped in a plastic laminate at the beginning of the main ripening and the cheese remains in this wrapping until the consumption ripeness is reached and a cheese without skin has developed.

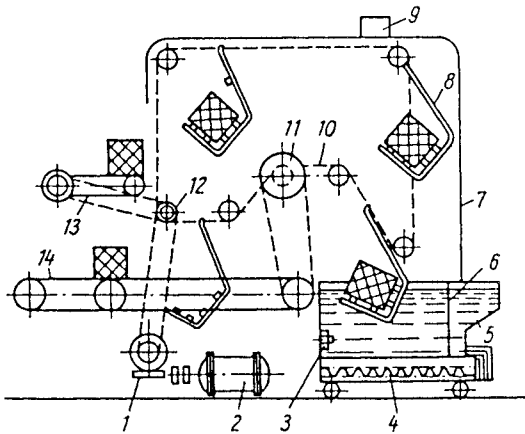


Figure 7./49 Scheme of a paraffination machine

(1) Gear box (2) Motor (3) Thermostat (4) electrical heating (5) Paraffination tank (6) Wire mesh (7) Housing (8) Cheese carrier (9) Vapor hood (10) Chain conveyor (11) and (12) Drive shafts (13) Conveyor belt (14) Discharge belt

Normally, packing is done immediately after salting in the brine tank. In order to accelerate the deacidification (basis for proteolytic activities), an additional curd salting is done (see 7.3.7).

Cheese types which would develop a dry skin when ripened normally, and whose surface properties are not part of their characteristics (such as Gouda or Chester), can be packed immediately after salting. Other types however, having a typical smear formation on the surface, e.g., Tilsiter, can be laminated only when the first surface treatment with their typical cultures has taken place, i.e., 5–10 days after salting.

Before packing, cheese remains for about 1–2 hours in a room with a low relative humidity to dry off the surface. Thereafter the cheese is placed in bags, closed with a metal clip or is sealed. They are shrink-wrapped immediately thereafter in either a water

bath or a shrink tunnel at 95 °C for 30–60 s, and the cheese is tightly surrounded by the laminate thus excluding air. The packed cheese is then transferred to a storage room where it ripens at 5–12 °C.

As the tightly packed cheese permits only limited growth of surface flora (for cheese with a smear formation), the taste and flavor of such a laminate-ripened cheese are less pronounced.

7.9. Dairy protein products

The manufacture of these products is not part of the cheese production. Protein products will be described in this section.

- Dairy proteins are manufactured from skim milk, buttermilk or whey in such a way that the milk protein is extracted in its entirety or in fractions from the other milk ingredients.

Milk protein consists of two fractions, casein and whey protein (see 2.3.1.3), which are different in function and structure. There are two variants for the production of milk proteins:

- a) Extraction of one or both separated fractions
- b) Extraction of the total protein

The prime objective is extraction of the casein fraction is of importance, as there are numerous applications for this product. In the food industry it is used as casein or caseinate. In the chemical industry casein is used in the manufacture of glue, stains, paints, filler in soap and paper manufacture; it is also a base raw material in the manufacture of plastics (casein-hardened formaldehyde) used for the production of buttons, combs, imitation marble or fake horn.

Whey proteins are manufactured mostly in the context of whey utilization, and the processes will be described in Section 10.3.2.1.

The extraction of the total protein (milk protein or casein-whey protein blend, also called coprecipitate) is of interest in the manufacture of foods such as bakery products, pasta, and meat products. Another field of application is in the manufacture of cosmetics. The processes are characterized by:

- a) Type of protein precipitation (by acid, coagulation enzymes and/or heat)
- b) Precipitation agent (e.g., lactic acid, citric acid, acetic acid, sulfuric acid, hydrochloric acid, calcium chloride, rennet)
- c) Separation process, e.g., by filters (bags, cloth) or centrifugation (decanter)

Products are also classified according to the type of precipitation, e.g. acid casein, rennet casein, as well as their function (e.g., water soluble milk protein, nutritional casein, rennet casein, caseinate).

The basis is skim milk in many cases, and for whey proteins it is de creamed whey. Therefore all products have a very low fat content (< 1.5% or < 2.5% in dry matter). Further, by applying proper processes (e.g., washing), the lactose content, the mineral content (declared as ash content) and the acid content can be reduced. Protein content is in the range of 70–80% (subject to the products) and the moisture content is 6–10%.

7.9.1. Manufacture of casein

In traditional batch-type processes, pasteurized milk is filled at coagulation temperature into a tank or cheese maker, and a coagulant (acid, enzyme) is added. Immediately after coagulation, the gel is cut, and the whey is removed while stirring slowly. After the whey has been removed, the curd is washed two or three times with warm water and is then filled into filter bags for setting the final moisture content. In a continuous process, the acidified product is blended with steam in a steam injector and casein coagulation is induced.

Another continuous process is shown in Figure 7./50. Skim milk goes from a buffer tank (2) via a pump into a plate heat exchanger (3), where it is heated to a coagulation temperature of 40–63 °C (subject to the coagulation reagent). By injection (4) of acid from a tank (1), the coagulation pH of 4.6–4.7 is set, and the mass is eventually heated to 50–65 °C. In a tubular holding section (6) milk is held until casein coagulates and is then separated from the whey in a tubular sieve (7). Thereafter there is the first washing with water with separation in a decanter (8). Casein from the first washing step is transferred with water into a tank (9) and is then recirculated through a sieve (7). Here the first wash water is removed, and fresh water for the second washing step is added. The washing temperatures are 30–35 °C. The final separation of the casein-water blend takes place in a decanter (8).

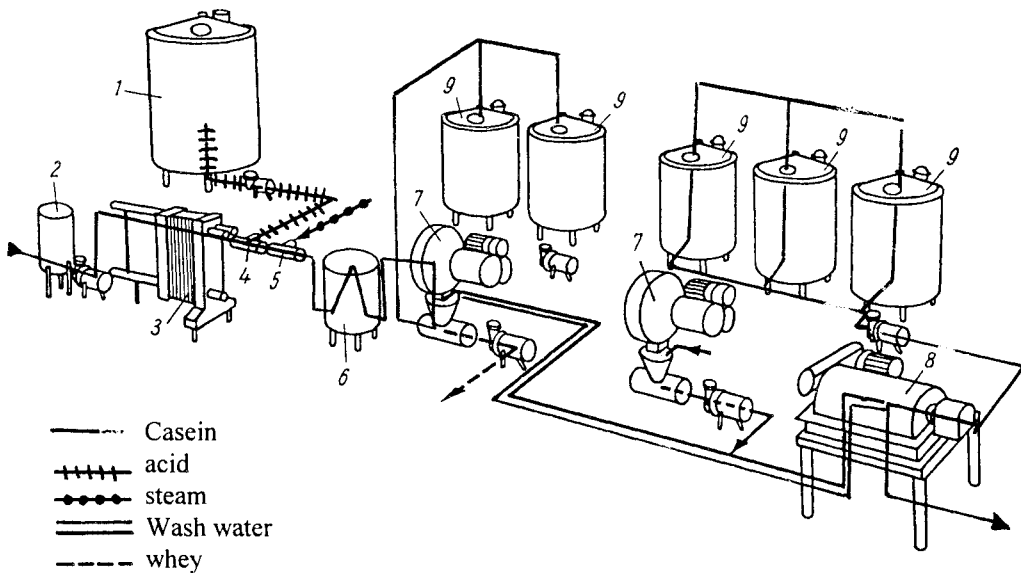


Figure 7./50 Process line for the manufacture of casein

(1) Acid tank (2) Buffer tank with floatation device (3) Plate heat exchanger (4) Acid injection (5) Steam injection (6) Tubular holding section (7) Rotating sieve (8) Decanter (9) Wash water tank

A decanter (Figure 7./51) is basically a horizontal centrifuge, and separation takes place in the horizontal conical-cylindrical bowl, where a transport screw rotates in the same sense as the outer shell but at a lower speed. The product enters a decanter at the smallest diameter of the rotor and is then pushed to the periphery of the shell. The liquid phase is removed and the solid phase is discharged by the transport screw.

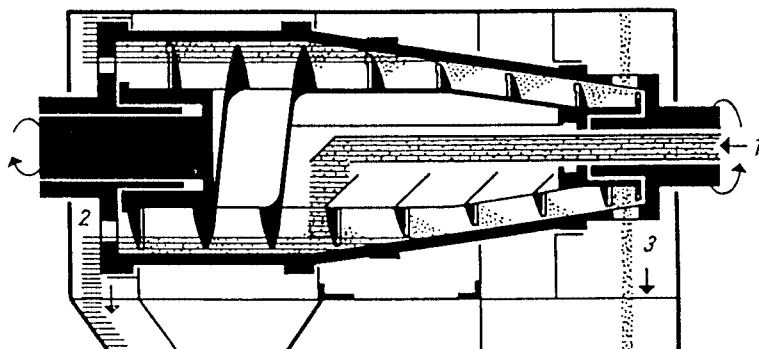


Figure 7./51 Decanter, type NX 314, horizontal view
 (1) Inlet (2) Discharge of liquid phase (3) Discharge of solid phase

During casein manufacture the washing serves to remove acid, lactose and milk salts. After reaching the desired dry matter level, casein is cooled and packed. A drying process can be linked to this process. For this purpose, acid casein is disintegrated to a uniform particle size and is deposited on a belt drier and dried slowly at a temperature of 50 °C; thereafter it is milled to a particle size of 0.5–1 mm and packed.

7.9.2. Manufacture of caseinate

Caseinate is a water-soluble casein which has been broken down with lye (NaOH) and is labeled sodium caseinate. For its manufacture, acid casein is blended with water and NaOH, and heated to 60 °C. The sodium caseinate solution should have a pH of 7 and a dry matter content of 20%. Then it is heated further to 90–95 °C and dried (mostly spray-dried, less often drum-dried; see 9.5.2.3), so that a sodium caseinate powder with a moisture content of 5% is produced. Sodium caseinate is easily dissolved in water and is used in many ways in the food industry.

7.9.3. Manufacture of coprecipitate

- Coprecipitate is denatured coagulated milk protein containing casein and whey protein.

For the manufacture of coprecipitate, the following aspects are of importance:

- a) High utilization of the total protein content of milk
- b) Increase of the nutritional value of foods by adding coprecipitate
- c) Wide field of application in the food industry

Manufacturing process. Several technologies are possible for the production of coprecipitate; in most cases the option of coagulation with calcium chloride/heat effect is selected. For this purpose, 1.5 g of CaCl₂ is added to each liter of pasteurized skim milk, and the product is heated indirectly to 80–98 °C in plate heat exchangers or directly by steam injection and held for some time until coagulation (fine particles) occurs. Thereafter it is separated in a decanter and the protein is washed several times. This product can

be dried directly on a belt drier or can be redissolved in water (by adding sodiumpolycarbonate) and spray-dried into a powder.

Coprecipitate can be manufactured in a plant as shown in Figure 7./50. The product can also be concentrated in a UF plant.



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8 Acidified Milk Products

8.1. Terms, importance and categories

8.2. Yogurt products

8.3. Kefir

8.4. Acidophilus milk

8.5. Buttermilk

8.6. Sour milk

8.7. Quality evaluation

8.8. Labeling, storage and transport



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8 Acidified Milk Products

8.1. Terms, importance and categories

- Acidified milk products are preparations made from pasteurized milk or pasteurized cream, sometimes enriched with nonfat dry matter and flavoring additives, and acidified by lactic acid bacteria, resulting in their typical texture.

All acidified milk products have one common characteristic, which is the presence of lactic acid, formed by the fermentation of lactose by various combinations of mesophilic and thermophilic lactic acid bacteria, leading to coagulation of milk protein (casein). For example, yogurt contains about 9.5 g / l lactic acid, which consists of the isomers L(+) lactic acid (left-turning, about 5.5 g/l) and D(-) lactic acid (right turning, about 4.0 g/l) (see also 2.3.1.8).

Other organic acids are developed in small amounts, such as acetic acid and—with fruit additions— malic, tartaric and citric acid. Further, very complex flavors develop with the main component acetaldehyde (especially in yogurt).

During lactic acid fermentation, lactose is not completely converted and lactose remains at a level of 2.5–4.0 g per 100 g product. This does not include products for which in the presence of lactose-fermenting yeast an alcoholic fermentation takes place simultaneously, producing ethanol besides the lactic acid (e.g., in kefir), in which case lactose is completely fermented.

Importance. Acidified milk products are well liked and contribute to a great extent to stabilizing stagnating milk consumption. Various ingredients result in a wide variety of products and can contribute to reducing caloric intake. Acidified milk products are sweetened with artificial sweeteners instead of saccharose, and they are made from skim milk and can be enriched with protein. Well-balanced nutrients and good digestibility, acid content and partial proteolysis contribute to the high dietetic¹ value of these products.

Types. Naturally acidified milk may have been one of the first milk products and the first acidified product. It is known by many names. In German-speaking areas it may be called Sauermilch, Setzmilch, Dickmilch, Satte, Stockmilch or Dickete.

These products have been developed mainly for climatic and ecological reasons and regional specific products have evolved which have found worldwide acceptance. For example, yogurt from Bulgaria or kefir and koumiss from the Caucasian region. Acidified milk products are classified into groups according to their specific characteristics. They are:

- a) Textural properties, such as solidified, stirred creamy, liquid (drinkable)
- b) Type of acidification cultures, e.g., mesophilic bacteria for a sour milk, thermophilic bacteria (mildly acidifying) for yogurt, bacteria-yeast blends for Kefir
- c) With or without fruit additives, resulting in terms such as fruit yogurt or natural yogurt
- d) Fat content of the product resulting in terms like cream sour milk, full-fat yogurt, skim milk yogurt

¹Dietetics (Greek): science of a sensible life style, especially involving healthy nutrition.

Product groups like sour milk, yogurt, kefir and buttermilk are evolving. Sometimes these products are called fermented milk products or blended milk products from fermented milk.

- Fermentation is a conversion of a substrate by a microorganism, by a vegetative or animal cell or by its enzymes into a product. In food production, the term fermentation is applied to the value addition and conversion of raw materials by microorganisms and enzymes into product ready for consumption.

All these products are manufactured from milk with a varying fat content and/or from skimmed milk. Buttermilk is an acidified milk product, which is a by-product of the manufacture of butter, and it is commercialized after proper treatment and eventual acidification, including the addition of ingredients.

8.2. Yogurt products

Over the last few years yogurt and its preparations have developed into one of the most well-accepted and consumed acidified products. A mildly acidic taste, good digestibility, variations in taste, and a high dietetic value as well as stable quality have contributed to this growth.

The initial solid natural yogurt has expanded into many new products. These include stirred yogurt (whose texture has been reformed by the addition of thickening agents), drinking yogurt with various additives (including an extended shelf life) and products such as protein- and lactose-enriched yogurt products. Combinations of typical acidification bacteria with, e.g., *Bifidobacterium bifidum* have resulted in products such as “Bioghurt” and “Biogarde,” which are characterized by good digestibility, low post-acidification performance, and taste stability over a longer time. Yogurt products can be freeze dried manner or spray dried (in hot air).

- Yogurt is a firm, creamy or liquid acidified milk product which is manufactured from pasteurized milk by using thermophilic lactic acid bacteria, whose growth optimum is at 38–42 °C. For increasing dry matter content, milk can be concentrated, or powder is added or milk is concentrated by UF. The standard “yogurt” is not heat treated after fermentation and does contain binding agents.
- Yogurt products or preparations are like yogurt, but contain flavor-imparting additives and binding agents and can sometimes be heat treated or preserved for shelf life extension.

The characteristic structural properties are as follows:

Firm yogurt	→	Firm gel in a pack, which is normally consumed by using a spoon.
Stirred yogurt	→	Gel has been broken, cooled and packed after coagulation; after packing a viscosity increase is observed, and the product resolidifies to a nearly solid texture, mostly by using thickening agents.
Drinking yogurt	→	Like stirred yogurt, but the product has been homogenized and brought into a liquid form before filling; does not contain thickening agents but contains stabilizers.

8.2.1. Technology of yogurt manufacture

This technology is characterized mainly by the type of product (firm yogurt, stirred yogurt or drinking yogurt), the kinds of ingredients that are added, and whether the shelf life is extended. A basic technology is shown in the flowsheet in overview 8./1. The basis is pretreated milk, which has been selected, cleaned, pasteurized and fat standardized. The selected milk must be free from inhibitors.

8.2.1.1. Starter cultures

A yogurt culture (consisting of lactic acid bacteria) is responsible for the acidification and fermentation of milk. Quality of the finished products depends upon culture composition and preparation to a large extent.

Composition of culture and effects. Starter cultures for yogurt should consist of thermophilic (heat-loving) bacteria with a growth optimum ≥ 42 °C, as they must be the dominant culture in the finished product, compared to mesophilic ones. Typical yogurt types are *Streptococcus salivarius subsp. thermophilus* and *Lactobacillus delbrueckii subsp. bulgaricus*, hereafter abbreviated *S. thermophilus* and *Lb. bulgaricus*.

These bacteria are very different in their morphology. *S. thermophilus* has spherical or ellipsoidal cells with a diameter of 0.7–0.9 μ m, growing pairs (diplococcus form) or medium-sized chains. *Lb. bulgaricus* grows in the form of relatively long rods of 0.2–0.4 μ m width, and has a tendency for string formation. Growth optimum for *S. thermophilus* is in the range of 38–42 °C and for *Lb. bulgaricus* at 42–45 °C. In a microscope the ratio of cocci to rods is visible.

- The ratio of *S.thermophilus* to *Lb. bulgaricus* should be 1:1 to 2:3 in a prepared culture (and in yogurt).

This ratio is given by the inoculation quantity, incubation temperature and time (fermentation time). After inoculating milk this ratio varies a few times and reaches the initial ratio at the end of the incubation period. Reasons are symbiotic relations (symbiosis refers to a community of different organisms and for their reciprocal advantage) between the types of bacteria.

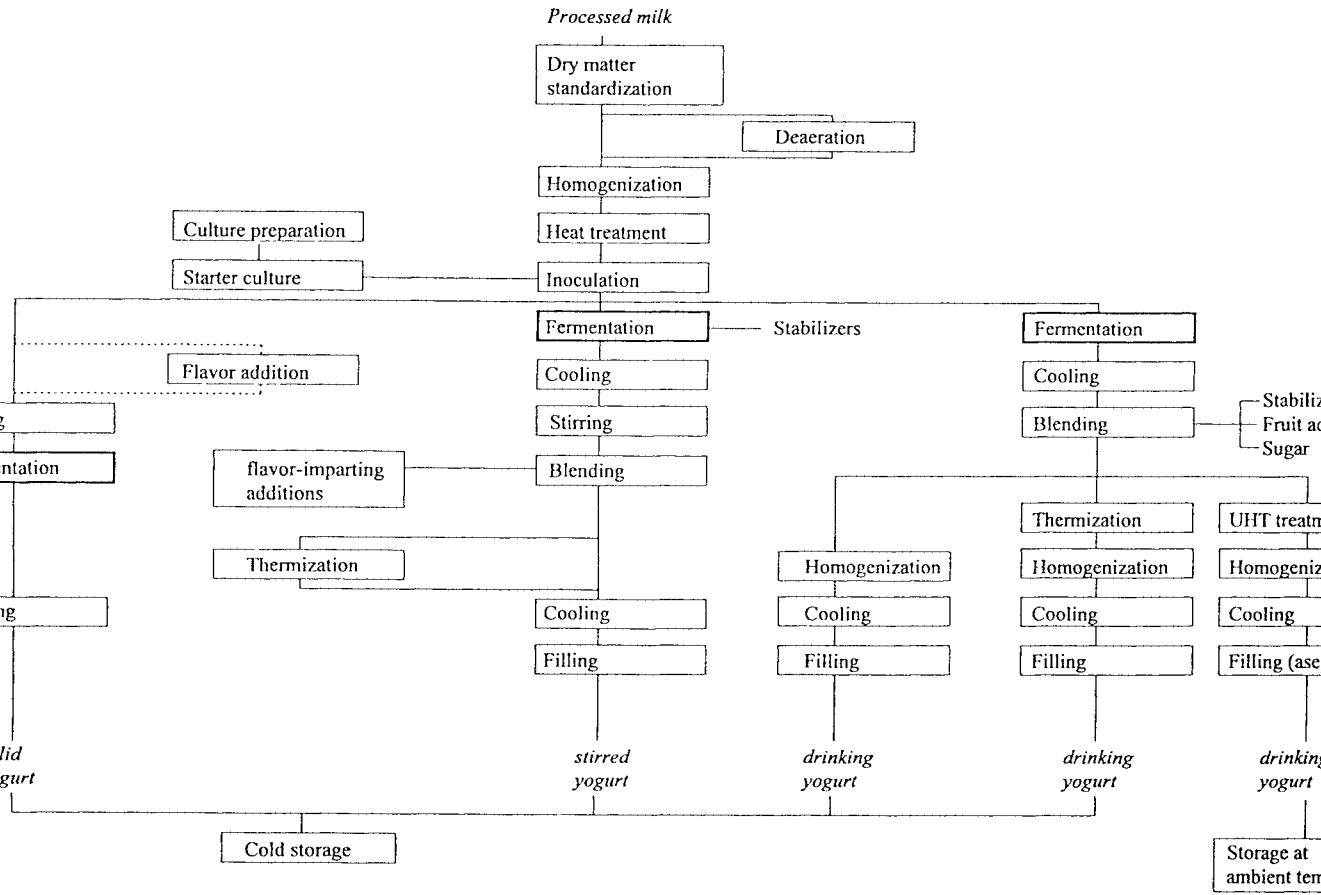
In this symbiosis, *S. thermophilus* initiates the lactic acid development by fermenting lactose and grows rapidly until a pH of 5.5 is reached. Good growth conditions are created by depletion of oxygen, acid formation and excretion of volatile compounds (e.g., formic acid) for *Lb. bulgaricus*.

Lactobacilli stimulate the growth of streptococci by their proteolytic action on milk protein and concurrent peptization, forming amino acids (threonine, methionine, valine). At the end the dominant flavor compound acetaldehyde (ethanol) develops in yogurt (Figure 8./1). At the same time, lactobacilli show lipolytic activity, liberating fatty acids and contributing to flavor development.

Besides the ratio of cocci to rods, the absolute total plate count (TPC) gives an indication on the quality of the culture. a good operational culture should have a TPC of 2–4 million per ml.

Another aspect is that during the fermentation the streptococci produce exclusively L(+) lactic acid (also formed in the human and animal body), whereas lactobacilli produce D(–) lactic acid or a blend of both isomers (depending on their strain) in certain ratios. In culture blends with strain variations of lactobacilli, the ratio of the preferred

Figure 8.1 Basic flowsheet for the manufacture of yogurt



L(+) lactic acid producing organisms can be influenced in yogurt. Another criterion is the starter potential, i.e., how rapidly acid can be formed.

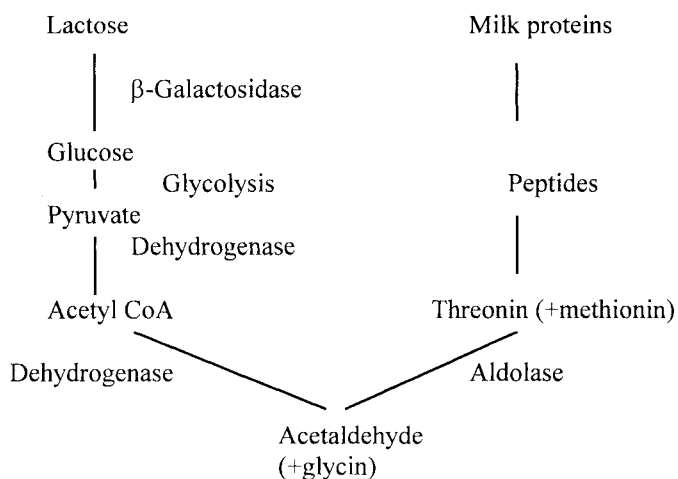


Figure 8./1 Development of acetaldehyde in yogurt

- Starter performance is related to the SH value which is achieved within 2 hours after inoculation of sterilized skim milk with 2% of a starter culture at an incubation temperature of 42 °C.

For mildly acidified yogurt, cultures are modified in such a way, that *Lb. bulgaricus* is replaced by other types of lactobacilli and bifido bacteria. Their growth optimum is 40–43 °C, and their acidifying capability is less pronounced, so that the desired acidity is achieved only after 6–8 hours. In most cases cultures with *Bifidobacterium bifidum* (forming L(+) lactic acid) and *Lactobacillus acidophilus* [forming L(+) and D(-) lactic acid] are used.

Culture preparation. This must be done under aseptic conditions in order to avoid contamination with yeast and mold, coliform bacteria and bacteriophage infections. Cultivation of a mother culture must be done under laboratory conditions; i.e., the preparation of the intermediary and operational culture is done in a separate room with suitable installations (see Figure 7./1).

A mother culture is prepared from a liquid or freeze-dried starter culture. Deep-frozen cultures or starter culture concentrates are utilized directly for the preparation of intermediary and operational cultures. Another possibility is to use direct starter cultures (deep-frozen or freeze dried) directly in yogurt. The most appropriate process must be selected on a case to case basis and is subject to the operational conditions in the production area.

For the preparation of yogurt culture, the following method can be chosen:

Preparation of an inhibitor-free milk, treated and dry matter standardized milk or recombined milk

↓

Heating to 90 °C for 30 min in the incubation tank

↓

Cooling to 43–45 °C

↓
 Inoculation with 2–3% mother culture
 ↓
 Incubation for 3 h to a pH of 4.5–4.65 and an SH of 36–42
 ↓
 Rapid cooling to temperatures below 15 °C

By varying the incubation temperature, the ratio of cocci to rods can be influenced, therefore influencing the fermentation profile as follows:

Temperatures < 43 °C stronger growth of cocci
 Temperatures > 43 °C stronger growth of lactobacilli

Another visible indication of the end of the incubation (fermentation) period is an acid coagulation of casein with formation of the yogurt gel at the isoelectric point of pH 4.65. This gel should show normal coagulation without whey separation.

8.2.1.2. Dry matter standardization

In order to obtain the desired gel structure in the yogurt with the desired typical consistency, the natural nonfat dry matter content DM_{ff} must be raised by 1–3%. The DM_{ff} modifications can be easily measured by the density. The selected range is 1.035–1.60 g/ml.

Low-fat or skim milk yogurt has a softer gel than a whole milk yogurt, therefore the dry matter content must be raised more. The relatively low dry matter content in yogurt preparations is adjusted to higher levels at a later stage. A DM increase can be achieved by removal of water (evaporation, enrichment by UF) or by the addition of milk powder or milk concentrate.

Water removal by evaporation. Water is removed under vacuum, as the product is treated more gently at the lower process temperatures, and a higher evaporation rate is achieved at a lower energy input. Vacuum evaporators are used for this purpose, which are similar to the one shown for cream deaeration (Figure 6./1). Water is removed at temperatures of 70–80 °C. The calculation of the processed milk quantities is shown in the example below:

Task: How many kilograms of milk with a fat content of 4.2% and a density of 1.028 g/ml can be concentrated to a density of 1.040 g/ml within 1 hour in a plant having a water evaporation capacity of 240 kg/h? What should the initial fat content be, if yogurt with a fat content of 3.5% is to be manufactured?

Solution: First the nonfat dry matter content of the raw milk DM_{ff1} and the yogurt milk DM_{ff2} must be calculated with known fat contents f_1 and f_2 as well as the lactodensitometer grades ld_1 and ld_2 . The fat content is given, the lactodensitometer grades must be calculated from the densities ρ_1 and ρ_2 as follows:

$$ld = \rho \cdot 1000 \text{ dm}^3/\text{kg} - 1000$$

$$ld_1 = 1.028 \cdot 1000 \text{ dm}^3 - 1000$$

$$ld_1 = 28$$

The density ld_2 is calculated in a similar way and a result of 40 is obtained. Calculation of DM_{ff} is done as follows:

$$DM_{ff} = \frac{ld}{4} + \frac{f}{5} + 0.55$$

$$DM_{ff1} = \frac{28}{4} + \frac{4.2\%}{5} + 0.55 = 8.39\%$$

$$DM_{ff2} = \frac{40}{4} + \frac{3.5\%}{5} + 0.55 = 11.25\%$$

From the known nonfat dry matter content we obtain the concentration degree c according to the formula

$$c = \frac{DM_{ff2}}{DM_{ff1}} = \frac{11.25\%}{8.39\%} = 1.34$$

The milk flow rate m_1 is given by the function

$$= 260 \text{ kg/h} \cdot \frac{1.34}{1.34 - 1} = 1025 \text{ kg/h}$$

This installation has a capacity to evaporate 1025 kg/h of raw milk. The flow rate for concentrated milk is calculated as follows :

$$= 1025 \text{ kg/h} \cdot \frac{1}{1.34} = 765 \text{ kg/h}$$

The required fat quantity for 765 kg milk is calculated as

$$FU = m \cdot f = 765 \cdot 3.5\% = 2678FU$$

The fat percentage of the raw milk is obtained after rearranging for f

$$f = \frac{FU}{m_1} = \frac{2678}{1025} = 2.61\%$$

Raw milk must be standardized to a fat content of 2.61%.

Water removal by membrane filtration. In this process, the dry matter of the entire milk flow is increased by ultrafiltration, or retentate is added. When concentrating the entire milk flow, a concentration factor of 1.4 is assumed. This milk shows good acidification performance despite a reduced lactose content, and the fermented yogurt has a relatively firm consistency. Retentate addition is comparable to a dry matter increase by adding milk concentrate.

Addition of milk powder or concentrate. In a batch preparation spray-dried skim milk powder is dissolved in milk of 40 °C in a ratio of 1:5, and this batch is added to yogurt milk while stirring well. When calculating the quantities, this amount must be considered. A continuous addition is done by dosing this premix or preferably milk concentrate into a milk flow, resulting in a homogeneous distribution of the added ingredients.

Calculation of the quantities to be added. The basis is the ratio of nonfat dry matter to density and the powder addition is calculated according to a formula. Moisture content of the milk powder is negligible. After adding the powder, the fat content must be determined in order to calculate the balance fat to be added via cream.

Task: 1025 kg milk (see previous task) with a density of 1.028 g/ml must be raised to a density of 1.040 g/ml. How many kg of milk powder must be added?

Solution: The difference in density between DM_{ff2} and $DM_{ff1} \approx 2.85\%$, i.e., dry matter DM must be increased by this amount.

$$1000 \text{ kg} \div 2.86 \text{ kg} = 1025 \text{ kg} \div x$$

$$x = \frac{2.85 \text{ kg} \times 1025 \text{ kg}}{100 \text{ kg}} = 29.3 \text{ kg}$$

About 29 kg of milk powder must be added.

Another approximate calculation can be done using the protein titer, where 1% of milk powder addition is equal to an increase of 0.3%. For a cross-check, the density of the milk must be determined.

Milk powder can be replaced by milk concentrate; this is done mainly in plants where milk is concentrated for the purpose of manufacturing long-shelf life products.

- After raising the density with milk powder or concentrate, yogurt milk must be pasteurized.

8.2.1.3 Deaeration

When incorporating ingredients, especially milk powder, some air incorporation in milk cannot be excluded, which is unfavorable for the product quality in many respects. Deaeration (air removal under vacuum) has the following effects:

- Viscosity increase and improvement of gel stability in the yogurt
- Removal of undesirable taste and flavor compounds
- Improvement of the homogenization effect
- Reduction of fouling in plate heat exchangers when heating yogurt milk

Vacuum vessels (as shown and described in Figure 6./7, Section 6.2.1.2) are suitable for deaeration.

- Deaeration is done at pressures of 0.7–0.8 bar at 70–75 °C.

When raising the dry matter content by evaporation, there is a simultaneous deaeration effect.

8.2.1.4 Homogenization

Homogenization of yogurt milk prevents creaming of the fat and improves the taste and consistency of the finished product. Complete homogenization results in a volume increase of casein particles, which can lead to a softer gel of the yogurt during coagulation. Therefore cream homogenization or a partial flow homogenization (see 4.2.4) is recommended, leaving the major part of casein unchanged.

- Homogenization is done at 150–200 bar at 58–60 °C.

In the production of drinking yogurt, a second homogenization after the acid formation results in a uniform liquid consistency with a reduced particle size and even distribution of the additions.

8.2.1.5. Heat treatment

Yogurt milk must be pasteurized according to an approved process. The normal short-time heat treatment does not result in a noticeable denaturation of whey proteins (which is necessary for good yogurt consistency), and an additional heat treatment of yogurt milk becomes necessary at higher temperatures and longer holding times. Figure 8./2 shows the time-temperature conditions which are required for 90–100% denaturation of the β -lactoglobulin.¹

- Manufacturing conditions at 90 °C and 5 min holding time are optimal and can be easily controlled.

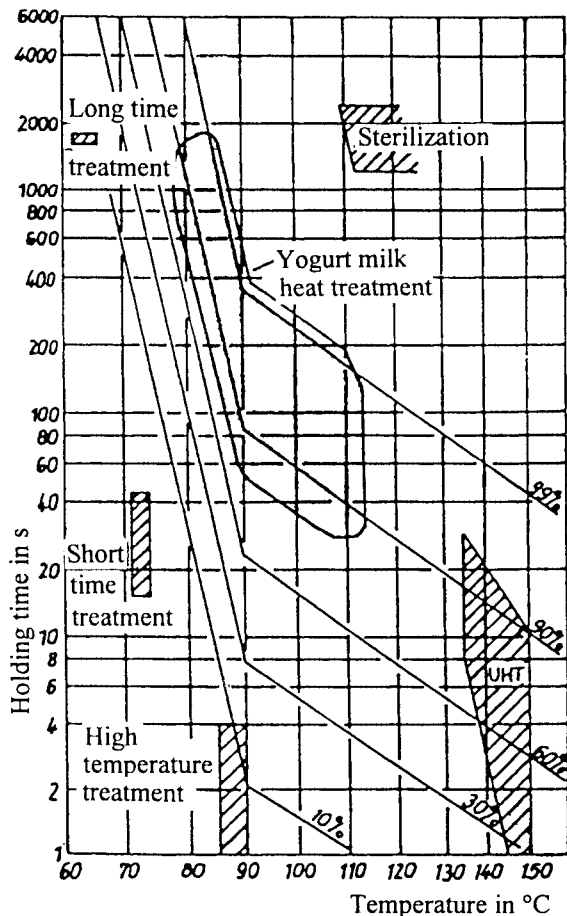


Figure 8./2 Areas of optimal yogurt milk heat treatment with an indication of the denaturation of β -lactoglobulin in %

¹ Huß, M., Beyer, H.J. and Kessler, H.G.: Fermentierte Milchprodukte—optimierte Joghurttechnologie. Die Ernährungsindustrie, 4/89.

These time-temperature conditions are also usable for culture preparations. Sometimes heating temperatures $> 100\text{ }^{\circ}\text{C}$ are encountered which lead to negative effects, partially impairing the casein and reducing the stability of the acid gel. Denatured whey proteins limit syneresis and have a countereffect on whey discharge from the gel. An additional heating can inactivate recontamination germs, increasing the product safety once more, and the yogurt flora can develop in a better way. Heating is done in plate heat exchangers with holding sections or in tanks equipped with stirring devices.

8.2.1.6. Inoculation

After heat treatment and concentration, milk is cooled down to $1\text{--}2\text{ }^{\circ}\text{K}$ above the incubation temperature, and is then inoculated with $1\text{--}3\%$ of the operational culture. Inoculation can be done continuously by dosing a culture into the milk flow (mostly done for a firm yogurt, as solidification takes place in the pack) or by adding culture to a fermentation tank.

8.2.1.7. Fermentation

Fermentation (see Section 8.1) is one of the key unit operations in yogurt technology, as characteristic properties are formed here. Milk is brought to the inoculation or fermentation temperature, which is at $40\text{--}45\text{ }^{\circ}\text{C}$ (subject to the culture). The incubation period is $2.5\text{--}3$ hours for standard cultures and $6\text{--}9$ hours for mildly acidifying cultures.

Inoculation initiates a lactic acid fermentation by enzymatic hydrolysis of lactose into glucose and galactose. Glucose is further decomposed via several steps into lactic acid. Galactose remains nonutilized as long as glucose and lactose are available for fermentation. Therefore galactose and lactose residues are found in yogurt. This phase of fermentation without a visible structural change is called prefermentation.

With a progressive pH decrease (< 5.0), an acid gel slowly develops, reaching its peak at the isoelectric point of pH 4.65, and this is called the main fermentation. With the development of a gel structure, a viscosity increase is observed, so that this process can be monitored by objective measurement. In general, the objective is a high viscosity, leading to a good water binding, and a typical consistency and countering whey discharge from the gel.

It is very important during gel formation to have no mechanical influences such as currents or shocks, which could disrupt the formation of the structure.

- During gel formation, milk must remain completely stationary.

During the acidification and gel formation, a typical yogurt flavor develops (its process has been described in 8.2.1.1). In this technology fermentation is designed as a batch process. The objective for all postfermentation activities is to design all installations and process steps in such a way that the gel is subjected to a minimum amount of external influence (e.g., utilization of tube pumps, optimal dimensioning of the pipelines, valves). Depending on the targeted product quality and installation configuration, incubation and fermentation are done as follows:

- a) In the sales pack (firm yogurt)
- b) In fermentation tanks (stirred and drinking yogurt)
- c) Continuous prefermentation in tanks and main fermentation in pack (firm yogurt)
- d) Continuous fermentation (mainly for stirred and drinking yogurt)

Fermentation in the pack. Milk is adjusted for temperature and inoculated and filled into the sales pack, where prefermentation and main fermentation take place by incubating in climatized rooms. This is a very gentle product treatment, as the fermentation process takes place after filling.

High energy and labor requirements for the operation of the air-heated and air-cooled climatized rooms or chambers are disadvantages. Loading is mostly done manually.

Incubation in the fermentation tank. This technology is the most common, as it is very favorable from an energy and labor point of view. Pretreated milk is filled at the incubation temperature into a fermentation tank (with stirring devices), is inoculated, other ingredients are added and is then fermented. It is advantageous to add the ingredients after fermentation, as it permits better control of the fermentation profile.

At the end of the fermentation, the gel is stirred, cooled to 30 °C in heat exchangers and then filled. In the pack there is another structural solidification, but the viscosity will not be the same as that of the nondestroyed gel at the end of fermentation. Therefore binding agents are added to increase viscosity.

Continuous prefermentation. This permits the manufacture of a firm yogurt under favorable energy conditions. Fermentation takes place in two phases:

- a) Prefermentation with an acidification to pH 5.2–5.0 (SH 15–20); the milk remains liquid.
- b) Main fermentation with acid coagulation of casein and gel formation, to pH 4.65 (SH 23–28).

The first phase takes place in an incubation tank, where after a starter culture is added and the desired pH is reached, milk is withdrawn continuously and replaced by fresh non-inoculated temperature-adjusted milk, and the pH value is kept constant. As starter culture is added only at the beginning of the prefermentation period, added quantities can be reduced by 90%. Prefermented milk is filled into sales pack and is transferred to climatized rooms, where the main fermentation into a firm yogurt takes place.

Continuous fermentation. This technology has rarely been implemented on an industrial scale. It requires special fermentation tanks, where the gel is formed in the shape of a plug flow. This continuous process requires a high degree of automation, but has advantages from energy and labor points of view.

8.2.1.8. Chilling

After fermentation, cooling must be done as rapidly as possible, so that post-acidification in yogurt is less than 0.3 pH units (SH 8–9)

- A temperature of 15–20 °C should be reached within 1–1.5 hours.

In the manufacture of stirred and drinking yogurt this requirement can be easily met, as a stirred gel can be cooled to the desired temperature in a plate heat exchanger. When incubating in climatized rooms, heat must be removed by cold air, which is less favorable from an energy point of view. After cooling to 15–20 °C, the main flavor development takes place within 2 hours. After this process is over, yogurt is cooled further to 5–6 °C, and is stored at this temperature until it is distributed.

8.2.1.9. Additives

In the manufacture of yogurt products or yogurt preparations (such as fruit yogurt), ingredients are added which should have a pleasant taste and flavor, but should not mask the yogurt flavor.

Ingredients can be fruit preparations (see 5.2.2) such as fruit syrup, jams, marmalades, fruit preserves, fruit jelly, fruit, sweetened fruit pulp, fruit concentrate, frozen fruits, sugar, natural flavors and colorants.

The level of addition of fruit preparations is 20–25% for fruit yogurt. In firm yogurt, fruit preparations are added before filling the milk into the pack, forming a visible deposit on the bottom, or the product is added after fermentation on top of the product. Flavors can be added to milk before fermentation. In stirred and drinking yogurt, the ingredients are added by dosing devices directly into the product flow or by stirring in a storage or process tank.

Stabilizers, thickening agents. Hydrocolloids are added as stabilizers or binding agents with the objective of stabilizing yogurt consistency and avoiding whey separation by gel syneresis. Many hydrocolloids, as described in Section 5.2.2, are suitable. In most cases gelatin (for cost reasons) and modified starch are used. For adding gelatin, a process such as that described in Section 5.2.2 can be used.

- The levels of stabilizing and thickening agent additions should be kept at <1%. The higher the dry matter in yogurt, the lower the levels of these ingredients.

8.2.1.10. Preservation

Yogurt manufactured under normal processing conditions has a minimum shelf life of 8–10 days at temperatures ≤ 10 °C, which is sufficient for normal marketing conditions. The trend for concentration of production and market expansion requires efforts to increase the shelf life to 3–4 weeks.

The same principles are applied as for increasing the shelf life of fresh cheese (Section 7.4.1.6). The same technologies can be applied:

- a) Aseptic production and filling
- b) Chemical preservation
- c) Thermal preservation

A key problem in the preservation of yogurt is a requirement in many countries that living cells of the typical microorganism must be present, if the product is to be labeled “yogurt.” Therefore aseptic production and filling are gaining importance despite the high investment costs. During thermal preservation the typical yogurt flora is significantly damaged, and during the UHT treatment it is completely inactivated.

Chemical preservation, mostly done by sorbic acid, prevents growth of harmful yeast and mold, and the typical yogurt flora is less damaged. In many cases food legislation limits or interdicts chemical preservation. Aseptic production and thermal preservation are described in detail below.

Aseptic production. The process must be configured in such a way that after a heat treatment of milk, contamination with other germs, especially yeast and mold and mesophilic bacteria, is excluded.

For this purpose, hermetically closed production installations are necessary which are kept sterile by cleaning and disinfection circuits. The aseptic fermentation tanks are operated with sterile air at normal or slightly increased pressures. Sterile air is produced in oil-free compressors and filtered for sterility (Figure 8./3).

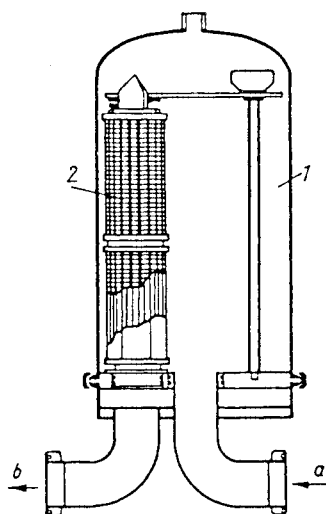


Figure 8./3 Sterile air filter

a) Air inlet b) Sterile air outlet

(1) Cover and distribution device (2) Filter insert

For the aseptic filling of yogurt into bottles and jars, installations are used as shown in Figure 8./4. The sterile section of the installation is formed as a tunnel, which is kept under a slight overpressure by using sterile air and can be cleaned with a CIP system. The precleaned and presterilized containers are transferred by conveyor belts (1) into the installation, where they are treated by a blend of H_2O_2 -steam in the sterilization section (2). The containers are turned in the rinsing unit (3), where they are rinsed with steam and sterile water (opening toward the bottom). After being turned back the containers reach the filling station (4) where the product is filled (quantity can be varied from 150–5000 ml). In the following closing section (5) the type of closure (screw, twist-off, plastic or aluminum seal) is applied (after presterilization) to the container and closed hermetically.

The aseptic filling into plastic cups is done in a similar way; the premanufactured cups and the laminate (used for in situ production of the cups) are sterilized with H_2O_2 , and dried with hot air. The oxygen content in the headspace of the filled cups and glasses can be reduced by steaming or gas flushing (e.g., CO_2), thus increasing the shelf life of the product.

A complete processing line for the aseptic filling and packing of glasses and bottles is shown in Figure 5./2 and described there.

Chemical preservation. Statements made in Section 7.4.1.6. about the preservation of fresh cheese apply here too.

Thermal preservation. Due to the low pH, the heating temperatures can be kept lower than during pasteurization. Thermization of stirred and drinking yogurt is done before aseptic filling, using time-temperature combinations of 60–65 °C and 8–10 s. Thereafter it

is cooled $<20^{\circ}\text{C}$. A thermization of firm yogurt in the pack is possible by raising the incubation temperature to $72\text{--}75^{\circ}\text{C}$ and holding for 5–10 min.

Completely sterile products are obtained by a UHT treatment before aseptic filling, resulting in a shelf life of >10 weeks at ambient temperatures. Hydrocolloids—mostly pectin or guar gum to stabilize the proteins, limit their contraction and counter a consistency degradation—are added before the thermal treatment.

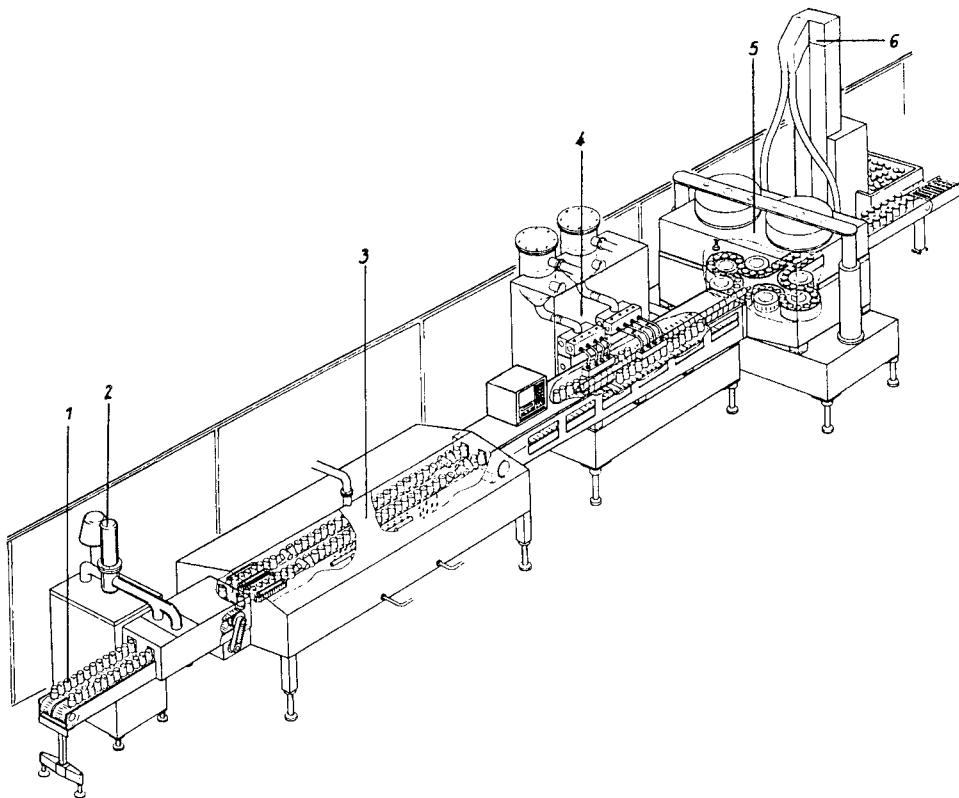


Figure 8./4 Installation for the aseptic filling of yogurt

- (1) Placement of the precleaned and presterilized jars (2) Sterilization section (3) Sterilization zone (4) Filling section (5) Closing section with lid magazine and lid sterilization

- Before heat treatment the hydrocolloids must be completely hydrated with casein particles; therefore the product must be held for 30–60 min after adding the hydrocolloids before it is heated.

8.2.2. Process lines for yogurt manufacturing

Below is a schematic description of process lines which can be used for the manufacture of yogurt, yogurt products and most of the acidified milk products.

Process line for milk treatment (Figure 8./5). Clarified fat-standardized, pasteurized and tempered milk goes into mixing tanks (1) and is then transferred by pumps (2) to a blending installation (3). Here ingredients such as milk powder and eventually sugar are added which are required for the batch. Milk is recirculated by pump (2) until the powder additions have been completely dissolved. Standardized milk is then transferred by pump (4) into the buffer tank (5) and by pump (6) into the plate heat exchanger (7). Here the milk temperature is raised to 78 °C by heat recovery from previously heated milk and by hot water. The hot milk then passes through a deaerator (for removal of air) and is then transferred by pump (10) to the homogenizer (11), and again through the plate heat exchanger, where the final heat treatment temperature is reached. After passage of the (12) energy is recovered from the hot milk and passed onto the incoming milk (from the buffer tank (5)), and is then cooled down to incubation temperature levels.

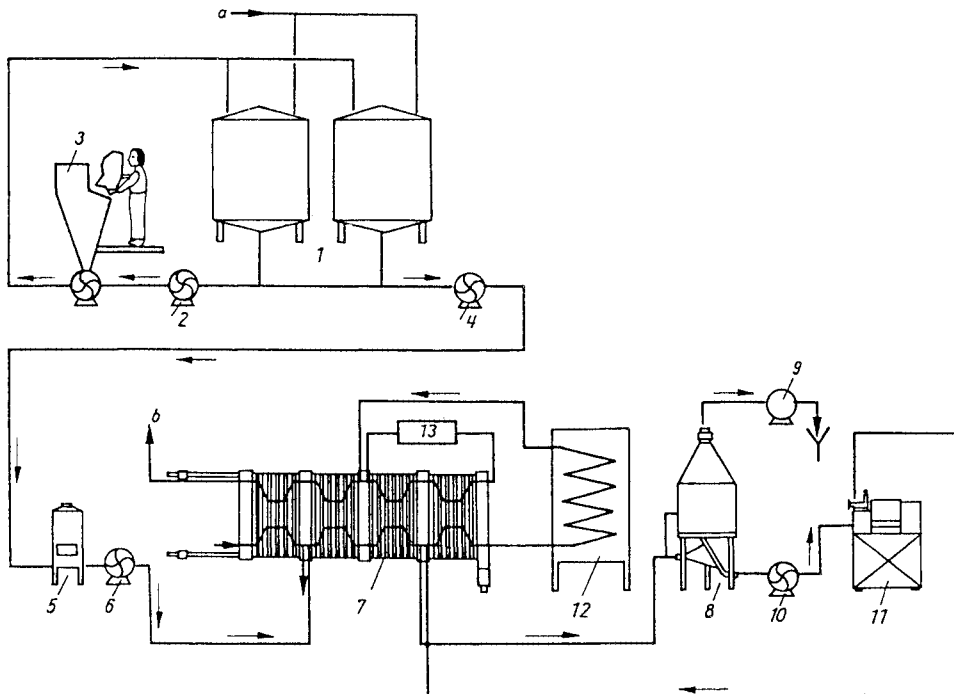


Figure 8./5 Process line for milk treatment

- a) Inlet of pretreated fat-standardized milk b) Outlet of milk for inoculation and incubation
 (1) Blending tanks (2) Circulation pump (3) Milk powder addition (4) Product pump (5) Buffer tank (6) Product pump (7) Plate heat exchanger (8) Evaporator (9) Vacuum pump (10) Product pump (11) Homogenizer (12) Tubular holding section (13) Hot water preparation

Process line for firm yogurt (Figure 8./6). Pretreated milk is stored in the insulated buffer tank (1), and then pumped with a displacement pump (2)—which controls the flow rate—to a filling machine (5). Ingredients such as flavors can be dosed from tanks (3) into the milk. Filled and sealed cups are assembled as transport packs, placed on pallets and transferred to the incubation rooms (6); after fermentation they are transported into cooling rooms (7).

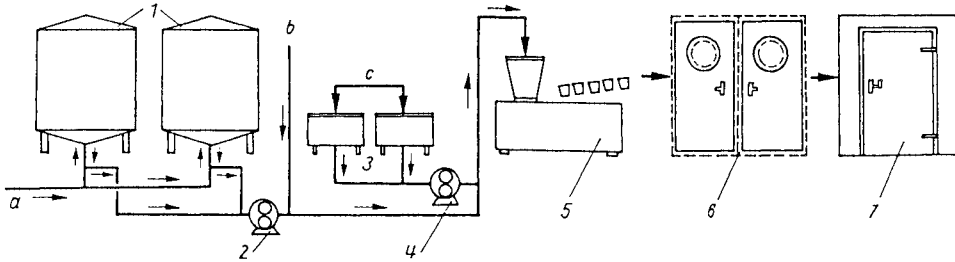


Figure 8./6 Process line for settled yogurt

a) Pretreated, standardized milk b) Starter culture c) Fruit flavor
 (1) Buffer tanks (2) Displacement pumps (3) Tanks for fruit flavor (4) Dosing pump (5) Filling machine (6) Incubators (7) Cold storage

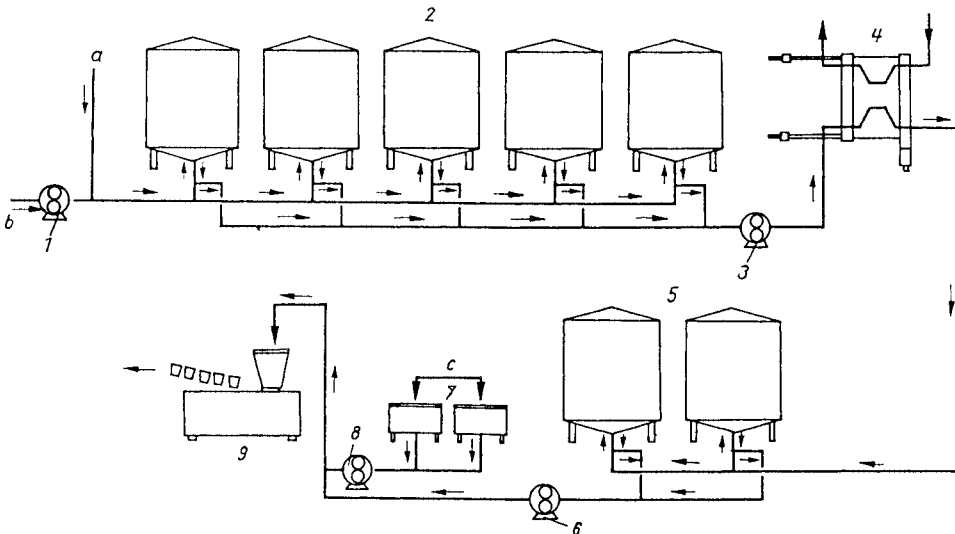


Figure 8./7 Process line for stirred yogurt

a) Pretreated, standardized and pretempered milk b) Starter culture c) Fruit additions
 (1) Dosing pump for starter culture (2) Incubation tanks (3) Displacement pump (4) Plate heat exchanger (cooler) (5) Intermediate storage tanks (6) Displacement pump (7) Tank for additions (8) Dosing pump for fruit additions (9) Filling machine

Process line for stirred yogurt (Figure 8./7). Pretreated milk is inoculated with starter culture by using a dosing pump (1) and is then transferred to fermentation tanks (2), where a complete fermentation takes place. In the tanks, the gel is stirred and transferred

with a pump (3) through a cooler (4) and brought to a temperature of about 15 °C. The number and volume of the fermentation tanks have been selected in such a way that discharge takes place after at most 30 minutes in order to avoid a too strong postacidification. Cooled yogurt is stored in a buffer tank (5) and then transferred by pump (6) to a filling machine (9). Other ingredients can be added with a dosing pump (8) on the way to the filling machine.

Process line for drinking yogurt (Figure 8./8). Pretreated milk is inoculated with starter culture in tank (1) and then transferred with pump (2) to the homogenizer after fermentation has been completed. Here yogurt is liquefied with a concurrent homogenization of additives and fat. The product is cooled to about 15 °C in a cooler (4), then reaches a buffer tank (5) and is then transferred to a filling machine (7).

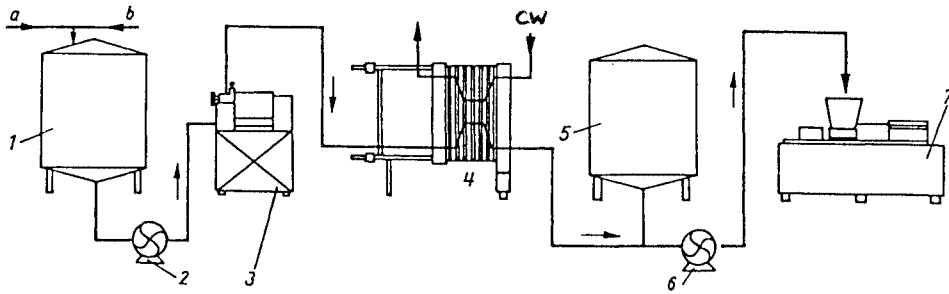


Figure 8./8 Process line for yogurt drinks

a) Pretreated, fat-standardized and pretempered milk b) Starter culture, fruit juice, sugar, stabilizer
c) Cooling water

(1) Blending and incubation tanks (2) Centrifugal pump (3) Homogenizer (4) Plate heat exchanger (cooler) (5) Buffer tank (6) Centrifugal pump (7) Filling machine

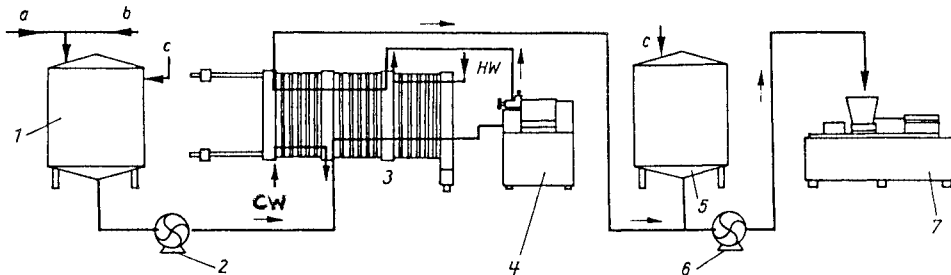


Figure 8./9 Process line for yogurt drinks, thermized

a) Pretreated, fat-standardized and pretempered milk b) Starter culture, fruit juice, sugar, stabilizer
c) Sterile air; (HW) hot water; (CW) Cooling water

(1) Blending and incubation tanks (2) Centrifugal pump (3) Plate heat exchanger (4) Homogenizer (5) Buffer tank (6) Centrifugal pump (7) Filling machine

Process line for thermized drinking yogurt (Figure 8./9). Yogurt is prepared on the process line as shown in Figure 8./8 and is thermized in a plate heat exchanger (3) by hot water, is cooled and transferred via a buffer tank (5) to the filling machine (7). In order to

extend the shelf life of the yogurt, the plant can be run in an aseptic mode, for which the incubation tank and the buffer tank are blanketed with sterile air (after the plant has been sterilized). Filling is also done aseptically.

Process line for drinking yogurt, UHT process (Figure 8./10). Fermented yogurt is stirred in an incubation tank (1), and is then transferred via a centrifugal pump (2) to a UHT plant. After UHT treatment it passes through an aseptic homogenizer (3), is cooled down to 15 °C and is then transferred via a sterile buffer tank (5) and a pump (6) to a sterile filling machine (7).

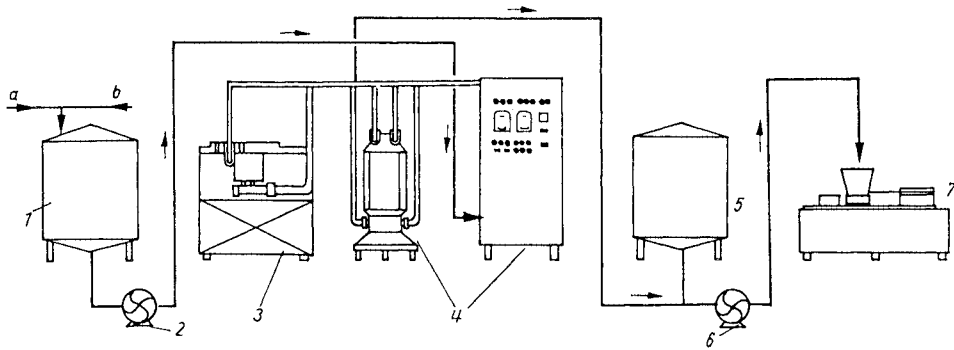


Figure 8./10 Process line for UHT yogurt drink

a) Pretreated, fat standardized and pretempered milk b) Starter culture, fruit juice, sugar, stabilizer
 (1) Blending and incubation tanks (2) Centrifugal pump (3) Aseptic homogenizer (4) UHT installation (5) Sterile tank (6) Aseptic centrifugal pump (7) Aseptic filling

8.3. Kefir

8.3.1. Terms

- Kefir is an acidic, slightly foamy product, made from pasteurized and fat-standardized or decreamed milk that has passed through a combined acidic and alcoholic fermentation of symbiotic lactic acid bacteria and yeast (“kefir grains”). It contains lactic acid, CO₂ and some ethanol and has a slightly yeast taste.

In finished products pH is < 4.65 and SH is 30–50, corresponding to a lactic acid content of 0.6–0.8%. The alcohol content in traditionally manufactured kefir is 0.5–1.0%; when using starter cultures it is 0.02–0.1%.

Key component of kefir are the so-called kefir grains (also “kefir mold”), which cause the fermentation. This organism has a network-like structure and a dry matter content of about 10%, consisting mainly of carbohydrates (56%) and protein (32%). Kefir grains contain fermentation organisms (mainly bacteria and yeast) of the following types:

Bacteria	Yeast
<i>Lactococcus lactis</i> subsp. <i>lactis</i>	<i>Saccharomyces lactis</i>
<i>Lactobacillus brevis</i>	<i>Saccharomyces cerevisiae</i>
<i>Lactobacillus caucasicum</i>	<i>Candida kefir</i> and others
<i>Lactobacillus acidophilus</i>	
<i>Lactobacillus kefir</i>	

Yeast form the network structure of the kefir grains and cause the alcohol and CO₂ development; bacteria cause acidification. As the composition of the microorganisms can vary widely, which results in different, often defective product qualities. Deep-frozen or freeze dried cultures are most commonly used in industrial manufacturing.

8.3.2. Technology

In a traditional manufacturing process, a “mother kefir” is prepared; i.e., a layer (5–10 cm) of wet kefir grains is spread at the bottom of a container. Then milk is added (20–30 times the amount of grains), which has been heated to 90–95 °C for min and cooled to 18–22 °C. During acidification over a period of 18–24 hours it is mixed two to three times and kefir swells and slowly rises to the surface. Upon reaching an SH value of 40, milk is passed through a fine sieve, which removes the kefir mold. It is then washed with water, and is used again in a new acidification process.

For preparing a drinking kefir, preacidified milk (kefir grains have been removed) is blended with 8–10 times the amount of fresh, nontreated milk, filled into bottles, closed (crown cap or others) and fermented for 1–3 days at 18–22 °C. During this period, another lactic acid fermentation takes place as well as formation of CO₂ and ethanol, which increases with the age.

Another technology consists of making an operational culture from a starter culture, and adding 1–5% to milk. This reduces the acidification or fermentation period to 12–15 h at 20–25 °C, until a pH of 4.4–4.5 is reached. For ergonomic reasons the ripening takes place in tanks or tempered vessels, and filling is done shortly before distribution.

Kefir manufactured in this way has a reduced yeast fermentation, resulting in less CO₂ and lesser filling problems (no blown packs). This kefir has a reduced yeast taste, is less acidic and less foamy, but is nevertheless a tasty acidified milk product.

8.4. Acidophilus milk

- Acidophilus milk is an acidic product made from milk with a standardized, slightly increased dry matter level milk. The typical fermentation agent is *Lactobacillus acidophilus* (*Thermobacterium intestinales*).

Culture preparation must be done with sterile milk, as *Lactobacillus acidophilus* has a very low resistance versus other germs due to its low acidifying ability. For the production of acidophilus milk, a selected, slightly concentrated and sterile milk must be selected. It is inoculated with 10% starter culture at 37–39 °C and then filled into bottles. Ripening is at 37–40 °C for 18–20 hours, and a very soft gel has developed with an SH of 30–35. The long acidification time and very soft coagulum (from which whey easily separates) are reasons for a very limited distribution and acceptance.

8.5. Buttermilk

8.5.1. Terms

- Buttermilk is a by-product of butter manufacture, made from pasteurized cream by the fat globule agglomeration process (see 6.2.3).

Subject to the raw material and the buttering process (sour cream or sweet cream), sour buttermilk (a classic acidified milk drink) or nonacidified (sweet) buttermilk (which has been acidified later in a controlled acidification) is manufactured.

- A buttermilk product is a product obtained after buttering of pasteurized cream, which reaches the consumer in an acidified form (either directly acidified or post-acidified by lactic acid cultures). It is made by increasing the dry matter content, fat standardization and/or enrichment with milk protein products.

Two different types of buttermilk products can be distinguished:

- a) Buttermilk—without enrichment of milk protein products and cream and without heat treatment after fermentation. Water added during buttering should not exceed 10% of the finished product; when using skim milk during buttering, added skim milk quantity should not exceed 15% of the product; fat content is $\leq 1\%$.
- b) Pure buttermilk—same as buttermilk, but without addition of water or skim milk for buttering; dry matter content increased by water removal; fat content $\leq 1\%$.

Apart from having the same dietetic and physiological properties as other acidified milk products, buttermilk has a relatively high content of phospholipids (lecithin), which originate from the membranes of the fat globules, and is supposed to have a positive effect on the human nervous system. The average phospholipid content of buttermilk is 0.14%, and the percentage of the total fat content is 15–30% in buttermilk.

8.5.2. Production of sour buttermilk

After separating buttermilk from the butter grains during buttering, a more or less intensive posttreatment is required, mainly for quality stabilization.

- Buttermilk must be chilled to $< 8\text{ }^{\circ}\text{C}$ immediately after manufacture.

Incorporation of air must be avoided at all costs during and after the production of buttermilk (which can lead to demixing of coagulated protein and serum and formation of a “deposit”). The transfer of buttermilk by centrifugal pumps and an open inlet into storage tanks is therefore of critical importance.

Homogenization of buttermilk leads to a uniform consistency and fat distribution, which helps in avoiding settling. Another criterion is the pH value, which should be below the range of 4.4–4.6. If the isoelectric point is not reached due to insufficient acidification, protein can precipitate in large flakes and rise to the product surface. For shelf life extension, the buttermilk can be treated at 63–65 $^{\circ}\text{C}$, and 0.2–0.3% of hydrocolloids are added.

Organoleptics. Flavor is a key quality criterion. A complex perception of flavor and taste results mainly from the metabolism of the microorganisms during cream acidification. A

significant taste defect is the so-called oxidized taste (also called metallic, oily, or cardboard-like). This is due to the oxidation of milk components such as phospholipids and triglycerides by oxygen, initiated by light and heat or by metallic ions in the buttermilk.

Other utilization. If buttermilk cannot be marketed for human consumption, other potential utilization are:

- a) Incorporation into buttermilk quarg
- b) Incorporation into other food
- c) Drying (manufacture of buttermilk powder)
- d) Utilization in animal feeding

8.5.3. Manufacture of acidified buttermilk

During the manufacture of sweet cream butter or mildly acidified butter, nonacidified cream is processed; therefore the buttermilk has a pH of >5.2 and does not have a sour taste. As this product is identical in its composition to sour cream buttermilk (has the same high nutritional quality), this buttermilk is processed into an acidified milk product in a controlled acidification by using mesophilic lactic acid bacteria, as used for cream acidification. The technology is similar to that for acidified milk (see 8.6.2).

A wide variety of buttermilk products can be manufactured in by increasing the dry matter content, adding flavor-imparting ingredients, and raising the fat content. The same conditions apply as in the production of yogurt products.

8.6. Sour milk

8.6.1. Terms

The range of acidified milk products is extended by products manufactured with mesophilic lactic acid bacteria. Products like Setzmilch, Dickmilch or Trinksauermilch are alternatives to buttermilk and yogurt. Cream-based sour milk products are well accepted in the culinary field. These products are manufactured with a liquefied or firm consistency, similar to yogurt fermented in packs.

- Sour milk is a product made from pasteurized, decreamed or fat-standardized milk or cream, which has been fermented to a pH value of < 4.65 by mesophilic lactic acid bacteria.

8.6.2. Technology

The process described below is typical for drinkable products. For firm products, basically the same technological parameters are applied with the exception that the product is fermented in the pack and that the gel remains in its original state.

Heating of milk to 85–95 °C for the coagulation of the milk proteins and eventually raising the dry matter level

↓

Setting of the fermentation temperature (19–25 °C), transfer of milk into fermentation tanks and inoculation with 1–2 % of starter culture

↓

Shock-free fermentation to pH 4.65–4.55 (SH 34–38)

↓

Stirring of the gel, eventual homogenization

↓

Cooling to 4–6 °C

↓

Filling into bottles, jars or one-way packs or wholesale packs

Homogenizing the milk after the heat treatment is advantageous, especially for high-fat products, and contributes to an improvement in consistency.

8.7. Quality evaluation

Sour milk products are evaluated in terms of organoleptic, chemical-physical and microbiological aspects. Organoleptic aspects of some sour milk products are shown in Overview 8./2. The chemical-physical tests cover fat content, dry matter content, pH value, SH value, eventually gel firmness, and foreign water content. A microbiological check covers yeast and mold, coliform bacteria and eventually foreign flora.

8.8. Labeling, storage and transport

Labeling. The same labeling principles apply for sour milk products as for market milk (see 5.1.4). Here we mention only some details, especially for yogurt.

The following labeling is prescribed:

- a) Designation—description of type, preparation in conjunction with type, e.g., “fruit yogurt” (yogurt with raspberries or others) for products where the fresh fruit percentage is $\geq 6\%$; “yogurt with fruit preparation” for products with a fresh fruit percentage of $\geq 3.5\%$; “yogurt with fruit flavor” for products with a fresh fruit percentage of $< 3.5\%$; fruits can be depicted accordingly.
- b) Shelf life markings.
- c) Name of manufacturer/distributor.
- d) Expiration date.
- e) Net weight—net weight at time of filling; all kind of net weights are possible
- f) Ingredients—e.g., for “fruit yogurt”: yogurt, fruit preparation with sorbic acid, binding agent, nature-identical flavor.
- g) Fat content—as “...fat in milk”; for skim milk yogurt this indication can be eliminated.
- h) Type of heat treatment (>50 °C), e.g., “UHT processed,” “sterilized,” “pasteurized.”

On one-way packs, markings have to be placed similarly to the depiction in figure 5./9. When using cups, the lid is used partially or completely for marking purposes; for other types of sales packs (wholesale packs, churns, bottles or jars) labels can be used.

Storage and transport. Sour milk products must be stored and transported in such a way, that they are not negatively influenced by their environment. Transport must be done without adding other products on the same platform. For storage purposes, temperatures ≤ 10 °C are selected.

Overview 8./2 Organoleptic characteristics and properties of some sour milk products

Type	Appearance	Consistency	Flavor	Taste
Whole milk yogurt	White to slightly yellow, gel-like	Firm	Clean, acidic, typical yogurt flavor	Clean, rich mouth feel, acidic, typical yogurt flavor
Skim milk yogurt	Chinaware white, gel-like			clean, acidic, typical yogurt flavor
Drinking yogurt from whole milk	Chinaware white to slightly yellow	Uniformly creamy		Clean, rich mouth feel, acidic, typical yogurt flavor
Drinking yogurt from skim milk	white			clean, acidic, typical yogurt flavor
Yogurt preparation from whole or skim milk	Color according to declared additives, which can be distributed differently gel-like		Clean, acidic, typical yogurt flavor, additives noticeable	Clean, rich mouth feel, acidic, typical yogurt flavor, declared additives noticeable
Buttermilk	Chinaware white, sometimes serum on top	Slightly creamy	Clean, acidic, flavorful	Clean, acidic, flavorful
Buttermilk preparation	Color according to additives, sometimes serum on top		Clean, acidic, additives noticeable	Clean, acidic, additives noticeable
Kefir	White to slightly yellow	Coagulated uniformly, some bubbles	Clean, acidic, slight yeast taste, typical kefir flavor	Clean, acidic, rich mouth feel, slight yeast taste, slightly refreshing



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9 Long-Life Milk Products

- 9.1. Terms and importance**
 - 9.2. Technology**
 - 9.3. Evaporated milk**
 - 9.4. Sweetened condensed milk**
 - 9.5. Milk powder**
 - 9.6. Labeling, storage and transport**
 - 9.7. Quality evaluation**
-



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9 Long-Life Milk Products

9.1. Terms and importance

- Long-life milk products are milk products made from milk, cream, or whey or dairy-based products that have been preserved by heat treatment or most often by water removal. Water removal can be done either by concentration and/or drying.

There are two major product groups of long-life milk products:

- a) Liquid products, such as sterilized or UHT processed cream (coffee cream, whipping cream), sterilized and UHT processed evaporated milk (sweetened and unsweetened), sterilized and UHT processed milk and milk products (e.g., sterilized milk, milk mix drinks such as chocolate milk).
- b) Dried powdered products such as milk powder (skim milk powder, whole milk powder), milk powder products (buttermilk powder, yogurt powder), whey powder (sweet whey powder, acid whey powder, demineralized whey powder), powdered milk preparations (infant formula, powder for calf feeding, dietetic powders, substitution products).

Very specialized technologies result in product groups such as freeze-dried products, block milk or block whey (manufactured by concentration, solidified by cooling) and extruded products.

A key aspect for the manufacture of long-life products is the extension of the shelf life and preservation of milk ingredients (components). This makes it possible to stock dairy products for complete market coverage and supply during critical times. It also serves to compensate for seasonal fluctuations in milk production, regulating the supply and covering dairy-based feeding requirements. Milk ingredients can be substituted in long-life products for animal-feeding purposes.

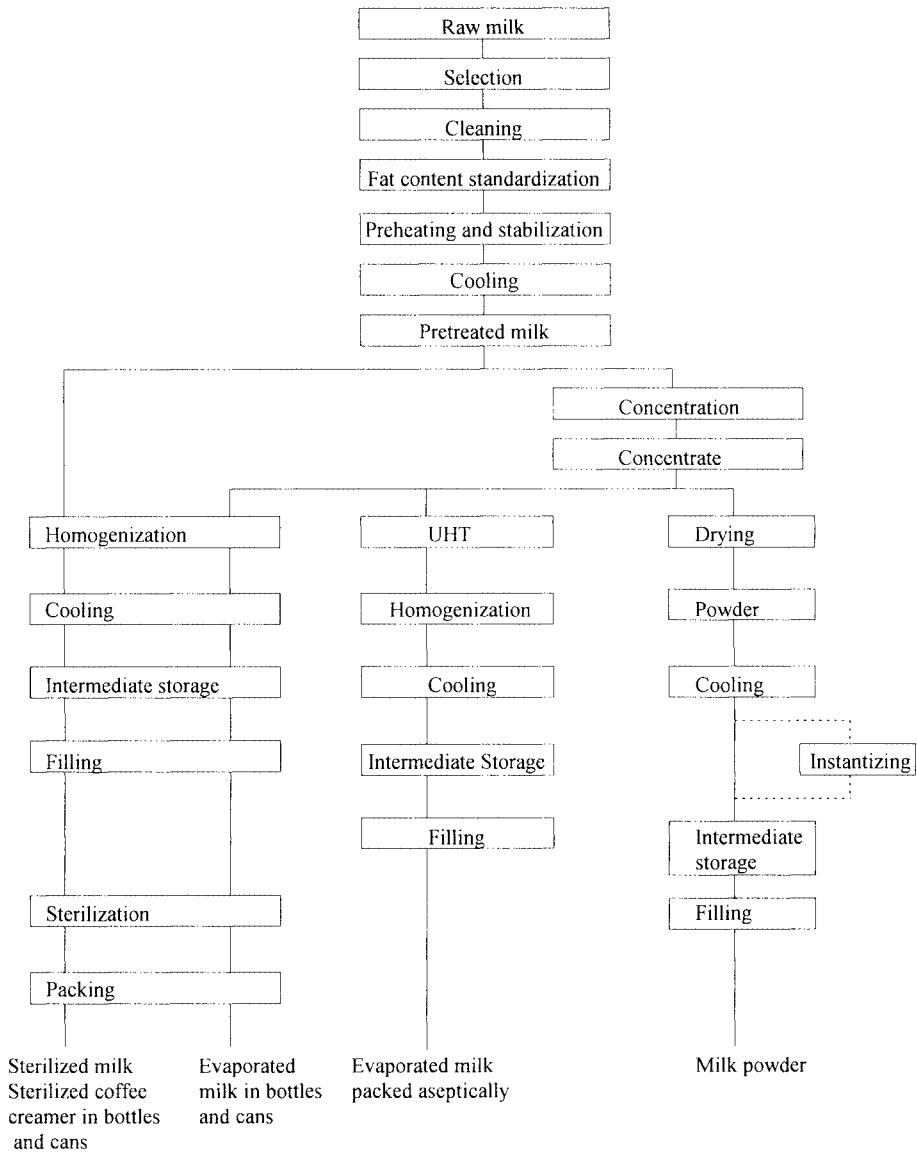
Another area of consumption, mainly for milk powder and whey powder, is in the food industry, such as in the manufacture of chocolate, bakery products, sweets, and meat and sausage products. Long-life milk products are also used for supplies to emergency areas and in catastrophes.

9.2. Technology

The technologies and unit operations for long-life products are less product specific but are based on general principles and laws of thermal process technology. The main reason is the scaling of the technologies and the large capacity of the installations, combined with high investments and a high degree of automation. An additional factor is the high energy requirement in the manufacture of long-life products; milk contains only 13% dry matter and large amounts of water must be removed. As previously indicated, the technology is oriented toward two process types (liquid and dry).

The selection of milk and pretreatment (in many cases concentration is common for all products) will be described in detail. Specific unit operations will then be described for each individual product. Basic unit operations in the manufacture of long-life milk products are shown in Overview 9/1.

Overview 9./1 Basic flowsheet for the manufacture of long-life products



9.2.1. Milk selection and pretreatment

Milk has to meet the same high quality requirements for use as market milk or in the manufacture of long-life milk products (see 2.7.3.2). The objective in manufacturing is complete germ inactivation, so the thermal load on milk is very high, which has negative effects on the proteins; on the other hand, a low level of microorganisms is advantageous.

Therefore milk has to meet the following requirements:

- a) Good casein stability to high temperatures, pH 6.4–6.7, SH < 7, no casein precipitation when mixed with 70% alcohol
- b) Low level or absence of thermoresistant microorganisms
- c) Low level or absence of anaerobe spore formers

Clarification. After selection, milk must be clarified, which is mostly done in separators, as this reduces the level of spore formers (which are specifically heavier). After clarifying, milk is decreased or standardized on fat. When manufacturing products with very specific and high quality requirements, e.g., infant formula (used for feeding babies), a bactofugation can take place after clarifying in order to reduce the level of spore formers.

Fat standardization. Fat content must be adjusted in such a way that after concentration of milk (or after drying) the finished product has the desired level, as corrections are not possible in many instances.

When calculating the fat content f_m of the raw milk, the nonfat dry matter DM_{ff} should be known (which can be assumed to be 8.9% on average). The fat content of the finished product f_p and its dry matter DM_p or nonfat dry matter DM_{ffp} should also be known.

From the determination of the concentration degree c (see 9.2.2) the fat content of milk is calculated as the quotient of the fat content of the product over the concentration degree.

Task: What fat content should be set for raw milk when a whole milk powder with a minimum of 26% fat and a total dry matter of 95% is to be manufactured? The nonfat dry matter in raw milk can be assumed to be 8.9%.

Solution :

$$c = \frac{DM_{ffp}}{DM_{ffm}} = \frac{DM_p - f_p}{DM_{ffm}} = \frac{95.0\% - 26.0\%}{8.9\%} = 7.75$$

$$f_m = \frac{f_p}{c} = \frac{26.0\%}{7.75}$$

As minimum fat contents are the basis in this calculation, it is recommended that the fat content be set to 3.4% in order not to have too low a fat content in the finished product.

Preheating and stabilization. Preheating (also called presterilization) is required mainly for liquid products, which are sterilized in the pack. The purposes of this operation are:

- a) Heat stabilization of proteins and avoidance of a viscosity increase and postthickening (gelation)
- b) Inactivation of vegetative recontaminating germs and inactivation of enzymes
- c) Temperature adjustment before concentration in an evaporator

The main objective is to counteract a tendency toward post-thickening in the product, which is basically a viscosity increase (can lead to gelation). The reason for this effect is the instability of casein during intense thermal treatment (high temperatures for long times) and a nonoptimal ratio of calcium-magnesium compounds to phosphorus-nitrate compounds in milk. Casein has a tendency to precipitate if milk is subjected to temperatures > 100 °C for a long time.

- Casein instability can be counteracted by denaturing whey proteins by preheating and adding stabilizing salts.

Casein can be stabilized by adding solutions of suitable salts or blends of salts before the preheating or concentration. Suitable stabilization salts are sodium and potassium hydrogen carbonate, calcium chloride, sodium and potassium citrate, sodium and potassium orthophosphate as well as sodium and potassium diphosphate.

- Casein stability can be improved during the manufacture of evaporated milk by adding maximum 0.2 g (for unsweetened) or maximum 0.3 g (for products with a DM >28%) per kg of phosphates or citrates or blends of these salts.

Due to their good solubility, di-sodium phosphate or sodium citrate is mainly used.

The optimal time-temperature combination for preheating must be determined by tests, as the milk composition varies seasonally and region-wise. Optimal time-temperature combinations for salt additions are 85–100 °C for 10–20 min or 110–130 °C for 40–50 s, with the latter profile being preferred due a better operational control. In most cases plate or tubular heat exchangers with holding sections are used. For UHT processed milk, it is sufficient to pasteurize the milk with a short-time or high-temperature process.

9.2.2. Concentration

To obtain a concentrate (old term “condensate”), the water content in milk must be reduced by 70%. This removal of water is also called concentration. Concentration is done by evaporating the water in suitable installations (evaporators), where the mass and volume are reduced and viscosity and density are increased. These parameters can be used for process control. Key aspects of milk concentration are:

- a) Minimum reduction of nutritional values and organoleptic properties
- b) Minimum steam and water consumption in these installations
- c) Good process control and easy monitoring

9.2.2.1. Basics

- Evaporation means the concentration of milk or liquid milk products; the water has to reach a boiling point; and the steam must have a pressure equivalent to ambient pressure. Vapor (steam) is removed by a draft, caused by a pressure differential.

In order to remove water from a solution in form of steam, the solution must reach the boiling point; the boiling points depends on the pressure (Table 9./1). Pressure p is the quotient of force F over the perpendicular area A or

$$p = \frac{F}{A} \text{ and the dimension is } \text{N/m}^2 = \text{Pa or bar}$$

The boiling point of all aqueous solutions including milk is above that of water. In order to evaporate, milk must be subjected to temperatures > 100 °C for a longer time, long enough to lead to significant product deterioration and a high energy requirement. Evaporation is therefore done below atmospheric pressure, i.e., in a vacuum, permitting a sufficient differential between the heating medium and milk, which is a basic requirement

for good flow conditions for the removal of vapor. This also reduces the energy requirement.

Table 9.1 Extract from the Mollier steam table

Pressure in			Temperature °C	Enthalpy of water		Enthalpy of steam		Evaporation enthalpy		Specific density of steam kg/m	Specific volume of steam m/kg
kPa	bar	atm		kJ/kg	kcal/kg	kJ/kg	kcal/kg	kJ/kg	kcal/kg		
4.9	0.049	0.05	32.6	136.5	32.6	2560.3	611.5	2423.8	578.9	0.0348	28.7200
9.8	0.098	0.10	45.5	190.5	45.5	2583.3	617.0	2393.2	571.6	0.0669	14.9500
49.0	0.490	0.50	80.9	383.3	80.8	2644.5	631.6	2306.1	550.8	0.3029	3.3010
58.8	0.588	0.60	85.5	358.0	85.5	2652.4	633.5	2294.4	548.0	0.3595	2.7820
68.6	0.686	0.70	89.5	374.7	89.5	2659.1	635.1	2284.3	545.6	0.4153	2.4050
78.5	0.785	0.80	93.0	389.8	93.1	2664.5	636.4	2274.7	543.3	0.4706	2.1250
88.3	0.883	0.90	96.2	403.2	96.3	2669.5	637.6	2266.3	541.3	0.5255	1.9030
98.1	0.981	1.00	99.1	414.9	99.1	2675.4	639.0	2260.5	539.9	0.5797	1.7220
117.1	1.177	1.20	104.2	436.7	104.3	2682.9	640.8	2246.2	536.5	0.6892	1.4510
147.1	1.471	1.50	110.8	466.8	111.5	2695.9	643.9	2229.1	532.4	0.8477	1.1780
196.1	1.961	2.00	119.6	504.1	120.4	2709.7	647.2	2205.6	526.8	1.1104	0.9910
245.2	2.452	2.50	126.8	532.6	127.2	2716.0	648.7	2183.4	521.5	1.3660	0.7320
294.2	2.942	3.00	132.8	560.6	133.9	2729.8	652.0	2169.2	518.1	1.6220	0.6170
392.2	3.922	4.00	142.8	603.7	144.2	2744.0	655.4	2140.3	511.2	2.1240	0.4710
480.3	4.803	5.00	151.0	638.9	152.6	2755.4	658.1	2116.0	505.0	2.6180	0.3820
588.4	5.884	6.00	157.9	669.5	159.9	2764.2	660.2	2095.1	500.4	3.1090	0.3210
686.5	6.865	7.00	164.0	695.4	166.1	2771.7	662.0	2076.3	495.9	3.5890	0.2780
784.5	7.845	8.00	169.5	716.4	171.1	2778.0	663.5	2059.1	491.8	4.0680	0.2455
882.6	8.826	9.00	174.4	740.2	176.8	2783.8	664.9	2043.6	488.1	4.5450	0.2190
980.7	9.807	10.00	178.9	755.5	181.5	2789.0	666.1	2028.9	484.6	5.0180	0.1980
1471.0	14.710	15.00	197.2	840.3	200.7	2807.3	670.5	1967.0	469.8	7.3520	0.1360
1961.3	19.613	20.00	211.3	902.3	215.5	2819.4	673.4	1917.1	457.9	9.6480	0.1037

9.2.2.2. Evaporator

The different types of evaporators can be classified as recirculation, falling film and plate evaporators, working either on a batch basis or continuously. There can be heat recovery (in single-stage plants by preheating installations or multi-stage plants by using the energy of the vapor from one stage to heat the following stage). For this purpose vapor are either compressed with new fresh steam or compressed mechanically. Compressed vapor (having a higher enthalpy and higher temperature) then again reaches the evaporator. Residual heat is used to preheat milk.

Batchwise operating plants are used in cases, in which the amount of water to be evaporated is small (i.e., yogurt milk) or other ingredients are added during the concentration, as they must have a defined dry matter level in the finished product (e.g., sweetened condensed milk). Larger plants are operated mostly in a continuous mode.

Evaporation installations can be either single-stage or multi-stage; a single-stage evaporator is a closed unit with a defined pressure and corresponding temperature. In multi-stage plants (up to seven stages), product from the first stage is transferred into the second stage and is heated with vapor from the first stage to the boiling point. This process makes it possible to reduce the steam consumption to a value of 0.08 kg steam/kg evaporated water.

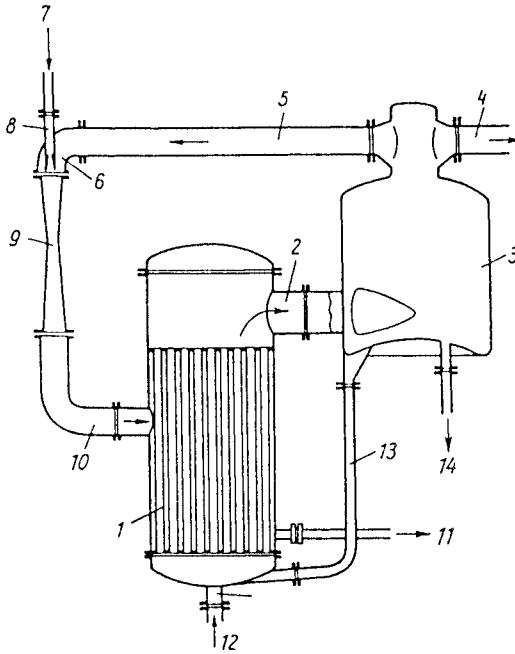


Figure 9./1 Single stage recirculation evaporator with vapor compression

(1) Heating section with heating tubes (2) Connecting duct for milk/vapor mix (3) Centrifugal separator (4) Vapor to condenser (5) Vapor to compressor (6) Steam injection compressor (7) Fresh steam (8) Steam injection port (9) Blending nozzle (10) Mix fresh steam / vapor (11) Condensate (12) Product inlet (13) Recirculation pipe (14) Concentrate outlet

Single-stage recirculation evaporator (Figure 9./1). Product is pumped into a tubular heating section of the evaporator from the bottom (12). Heat is added to the steam-vapor mix via a pipe (1), and the product rises in the tubes to the top, reaches the boiling point and goes via a connection into a centrifugal separator, where the liquid and the vapor are separated. Concentrated product leaves the separator via a pipe (14). If the desired concentration has not been reached, it is refed to the bottom via a recirculation pipe (13), mixed with fresh product and can be recirculated again. Part of the vapor is transferred via a pipe (5) to the steam injection compressor (6) mixed with steam (injected via a port (8) in a mixing nozzle (9), where the enthalpy is raised, and transferred to the evaporator heating section; the balance of the vapor are transferred via a pipe (4) to a condenser. Flow for the liquid and the vapor is shown in Figure 9./2. This evaporator has a maximum capacity of 1000 l/h of water.

The product can be recirculated several times in the same evaporator stage (especially in multistage evaporators), or it can leave after one passage. This results in different residence times and a thermal loads and can have disadvantages for sensitive products such as milk.

Falling film evaporator. Product residence time in falling film evaporators is always the same. Product is pumped into the top of the evaporation stages and passes through the tubes in a thin layer (on the walls). This has the following advantages:

- a) Product passage with short contact times on the heated tubes
- b) Good heat conduction due to thin product layer
- c) Uniform residence time and therefore no different thermal load

These plants can be operated with direct steam injection without vapor compression, with thermal vapor compression (steam injection) or mechanical vapor compression (turbo compressors, high-capacity fans).

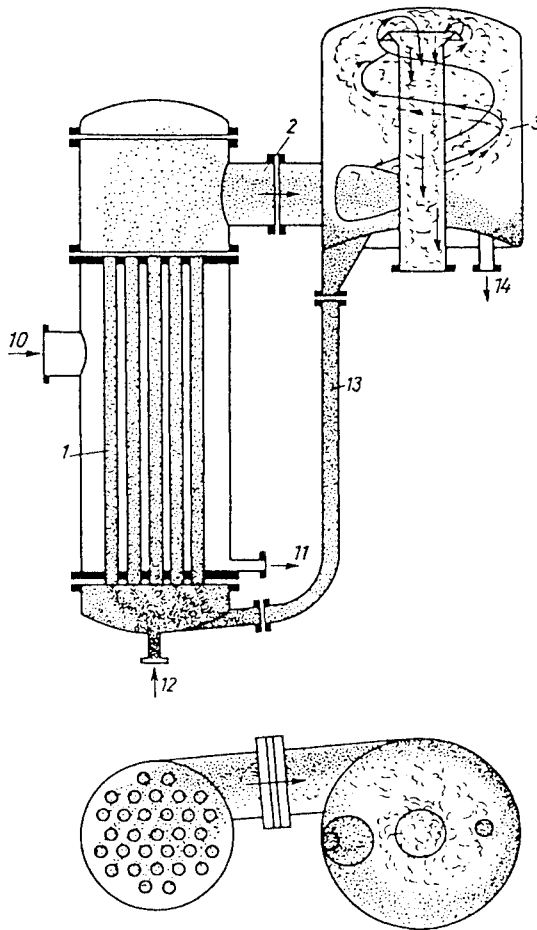


Figure 9.2 Flow patterns in the heating section and separator of the evaporator of Figure 9.1

Direct steam injection is of interest only in small plants, as the enthalpy of the vapor is waste heat and cannot be used for the evaporation process. Heat can be recovered in separate installations only before or after the evaporation.

For thermal vapor compression, vapor and fresh steam are mixed, increased in pressure, temperature and enthalpy and transferred to the evaporator, thus reducing the fresh steam consumption and the residual vapor significantly and allowing a large part of the heat to be recovered.

Energy utilization can be further increased by mechanical vapor compression or a combination of mechanical and thermal vapor compression, and the plant efficiency can be increased. Figure 9.3 shows a turbo compressor, which is driven by a gas engine (using a clutch and a gear). The compressor sucks the vapor from the last evaporator stage at 200 mbar and 60 °C, compresses it to 325 mbar at 71 °C and transfers it to the first stage. In a three-stage plant, this gives a differential of slightly less than 4 °C for each stage, which is sufficient with a sufficiently large heat exchange surface.

At the same time, the water circuit absorbs heat from the motor exhaust gases, which increases the water temperature from 80 to 85 °C. This circulating water delivers part of its heat to the prewarmed milk (prewarmed by concentrate) in a plate heat exchanger, thus reducing the water temperature to 65 °C. At this temperature it serves to cool the motor

and reenters the exhaust gas heat exchanger. This figure also shows power requirements and output in kW and percent.

This operation which is more economical from an energy point of view, requires a higher investment on the compressor side.

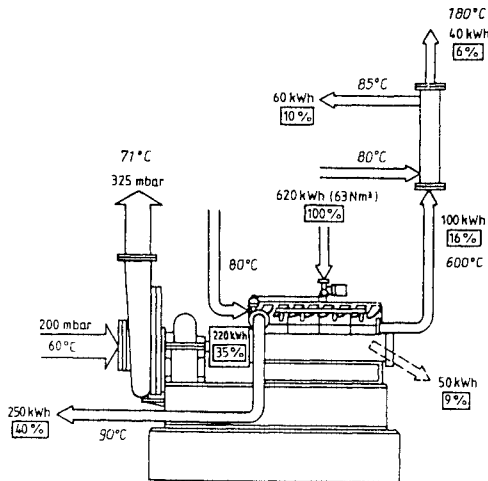


Figure 9/3 Mechanical vapor compression

Figure 9/4

Heat flow in a triple-stage evaporator : flowrate 37 t/h skim milk with 30 t/h water evaporation

a) Direct heating b) Thermal vapor compression c) Mechanical vapor compression
I, II, III evaporator stages

(1) Steam-injected vapor compressor (2) Mechanical vapor compressor

A Product to be evaporated **B** Vapor **C** Concentrate **D** Steam (fresh steam) **E** Condensate

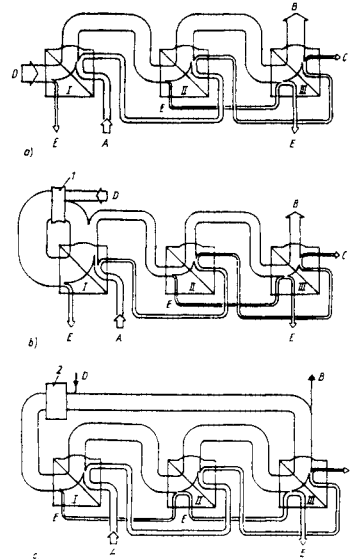


Figure 9/4 shows the energy flow for the different heating systems for evaporators.

Design and operation of a falling film evaporator type 476.803 FS (Figure 9/5). Milk that is to be concentrated is transferred by a pump (P1) from the buffer tank to a tubular preheater (V1 to V4). Installing the preheaters in the upper sections of the evaporators and condensers results in optimal energy utilization. Product is heated to 75–80 °C, and is transferred by pump P5 to a tubular preheater (H1 and H2), where preheating takes place at 110–130 °C (as required for evaporated milk). This preheating is eliminated when concentrate is used for drying.

Steam pressure of the hot milk is reduced in the flash vessel (I), cooled to evaporation temperature and then evenly distributed into the tubes by a distribution device, installed in the upper part of the evaporator above the calandria. The product flows downward in the tubes in a very thin film, is heated by the vapor (on the other side of the tube wall), and a part of the water evaporates. The vapor-liquid mix reaches the centrifugal separator (B1), from which the product is transferred by pump P2 into the second evaporator stage (A2), where the process of stage 1 is repeated. Vapor is extracted and compressed.

A further concentration takes place in the third stage of the evaporator A3. Part of the concentrate can be recirculated (in stage 3) by using pump P4 in order to have a more uniform product load and control or to further increase dry matter content. Concentrate is transferred by pump P7. The plant is put under vacuum by a steam jet-operated vacuum nozzle D; steam jet compressors F1 and F2 compact the vapor and transfers it into the evaporation stages; residual vapor is condensed in a surface condenser (K).

When manufacturing evaporated milk, the plant has a water evaporation capacity of 6000 kg/h, using a total of 1664 kg steam and requires 38 kW electrical power. Milk dry matter is increased to 24%, and the milk flow rate is 12,000 l milk per hour.

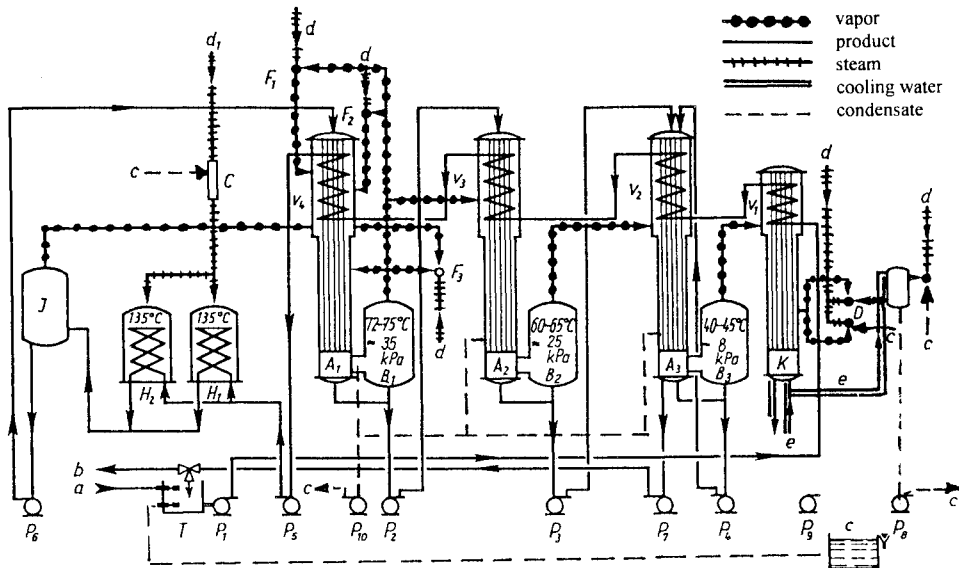


Figure 9/5 Falling film evaporator, type 476.803 FS (4) A for 5000 kg/h water evaporation

a) Fresh milk inlet b) Concentrate outlet c) Condensate d) Steam d1) Vapors e) Cooling water
 (A1) Evaporator stage 1 (A2) Evaporator stage 2 (A3) Evaporator stage 3 (B1) Centrifugal separator stage 1 (B2) Centrifugal separator stage 2 (B3) Centrifugal separator stage 3 (C) Steam cooler (D) Steam jet aspirator (F1) (F2) (F3) Steam jet vapor compressor (H1) (H2) Tubular preheater (I) Pressure reduction vessel (K) Surface condenser (P1) Centrifugal pump for fresh milk supply (P2) Centrifugal pump for product transfer from centrifugal separator 1 to evaporator stage 2 (P3) Centrifugal pump for product transfer from centrifugal separator 2 to evaporator stage 3 (P4) Centrifugal pump for product transfer from centrifugal separator 3 to evaporator stage 3 (P5) High-pressure centrifugal pump for fresh milk transfer to preheater (P6) Centrifugal pump for fresh milk transfer from pressure reducing vessel to evaporator stage 1 (P7) Centrifugal pump for concentrate discharge (P8) (P9) Condensate pumps (T) Feed tank (V1) (V2) (V3) (V4) Fresh milk preheater

Plate evaporator (Figure 9./6). This continuously operating type is designed differently by having the heat transfer and evaporation in a plate heat exchanger and not in a calandria (tubular heating section). The differences and distinctions are:

- Low installation height
- Short contact time between product and plates
- Flexible capacity by increasing or reducing plates
- Easy cleaning

After heating the product that is to be concentrated, the concentrate/vapor mix reaches a drum-shaped centrifugal separator, which removes the concentrate or transfers it to an-

other stage. Vapor can also be compressed and reused for heating of the evaporator. The flowsheet of a plate evaporator is shown in Figure 9.7.

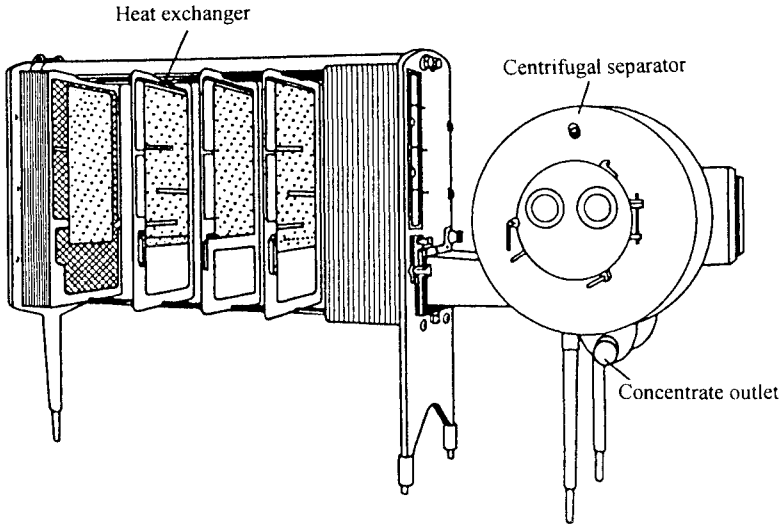


Figure 9.6 Plate evaporator, opened

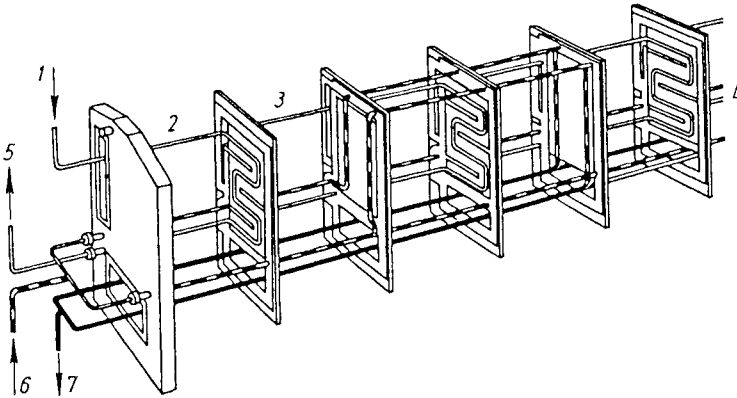


Figure 9.7 Flowsheet plate evaporator

(1) Steam inlet (2) Steam section (3) Vapor section (4) Return flow plate (5) Condensate discharge (6) Milk inlet (7) Concentrate outlet

Condensation of residual vapor is done in condensers, of which mainly two types are used: surface condensers (Figure 9.8) and mixing condensers (Figure 9.9). The difference in design and principle is mainly, that in the cheaper mixing condenser the vapor are condensed by mixing with cooling water, whereas there is no mixing in the surface condenser. Here the cooling water flows through a system of tubes, on whose surface the vapor are condensing.

9.2.2.3. Equipment and characteristics

The evaporator controls the capacity of the entire processing line.

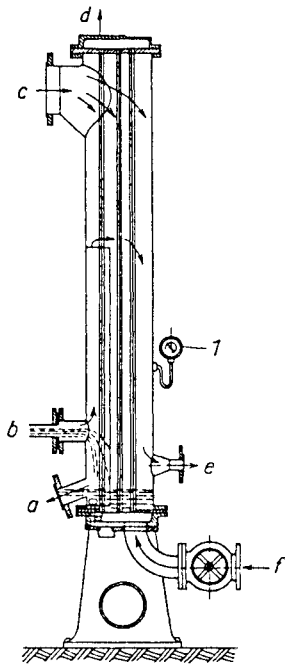


Figure 9/8 Surface condenser

- a) Condensing water b) Condensate/air mix
 c) Vapor d) Cooling water e) Air
 f) Cooling water
 (1) Thermometer

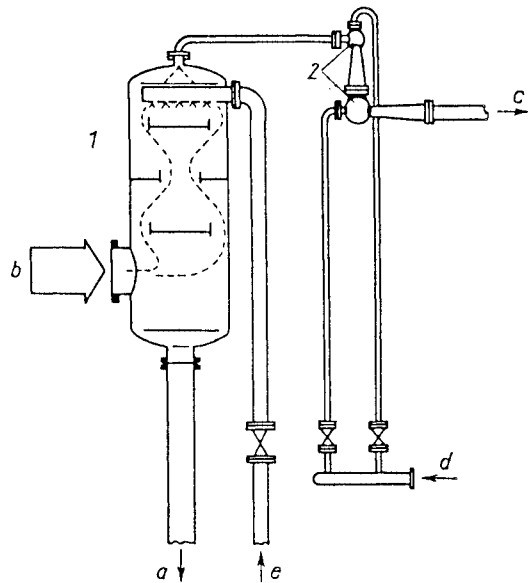


Figure 9/9 Mixing condenser

- a) To water pressure gauge b) Vapor from evaporator
 c) Vapor for preheating d) Fresh steam e) Cooling water
 (1) Condenser (2) Steam jet air ejector

- The capacity of an evaporator is expressed in kg water evaporated per hour.

For the manufacture of evaporated milk, mostly two- or three-stage evaporators are used having 4–6000 kg water evaporation per hour; for manufacturing concentrate for drying, installation with 10–20,000 kg water evaporation per hour are used; for whey concentration, the evaporation rate increases to 30,000 kg/h. A very important parameter is the steam consumption for evaporating 1 kg of water.

- The specific steam consumption is 0.3–0.6 kg steam per kg of evaporated water.

This parameter includes the entire steam consumption, including preheating and vacuum generation. Another parameter is cooling water consumption, which indicates the economy of the plant. Although a major part of vapor enthalpy is recovered, part of the vapor (residual vapor) must be condensed with water.

- Specific cooling water consumption is 8–10 kg per kg evaporated water, with a cooling water temperature of 15 °C.

9.2.2.4. Control of evaporation and concentrate

Evaporation is assumed to be finished when the concentrate has reached the desired level of dry matter content. As the dry matter content is proportional to the specific density, this parameter is used for control of the concentrate. Sometimes the lactodensi-

tometer is replaced by a Beaumé spindle. A comparison between °Bé and g/ml at 15 °C is shown in Table 9.2. Another indication of product quality is the degree of concentration.

- The degree of concentration is the factor by which the initial dry matter content has been raised.

Table 9.2 Comparison of °Bé and g/ml at 15 °C

°Bé	$\rho \geq 1$ in g/cm ³	$\rho \leq 1$ in g/cm ³
0	1	1
5	1.036	0.976
10	1.075	0.935
15	1.116	0.906
20	1.161	0.878
25	1.21	0.852
30	1.262	0.828
35	1.32	0.805
40	1.383	0.783
45	1.453	0.762
50	1.53	0.743
55	1.616	0.724
60	1.712	0.706
65	1.82	0.689

The concentration ratio CR can be derived from the function for c (see also 9.2.1)

$$c = \frac{DM_M}{DM_C} \quad \text{or } CR \text{ is basically } 1:c$$

DM_c dry matter of concentrate in %

DM_m dry matter of milk in %

\dot{m}_c mass flow rate of concentrate in kg/h

\dot{m}_m mass flow rate of milk in kg/h

If the concentration ratio CR is known, then the basic parameters can be calculated approximately according to the formulas:

Given	Objective	Formula
\dot{m}_M (flow rate of milk)	\dot{m}_W	$\dot{m}_W = \dot{m}_M \cdot \frac{c-1}{c}$
	\dot{m}_C	$\dot{m}_C = \dot{m}_M \cdot \frac{1}{c}$

\dot{m}_W (flow rate of evaporated water = flow rate of vapor)	\dot{m}_M	$\dot{m}_M = \dot{m}_W \cdot \frac{c}{c-1}$
	\dot{m}_C	$\dot{m}_C = \dot{m}_W \cdot \frac{c}{c-1}$
\dot{m}_C (flow rate of concentrate)	\dot{m}_M	$\dot{m}_M = \dot{m}_C \cdot c$
	\dot{m}_W	$\dot{m}_W = \dot{m}_C \cdot c - 1$

The evaporation process must be controlled in such a way that the desired dry matter content or concentration degree is reached. For this purpose the following process parameters must be considered:

- a) Pressure and temperature of the first evaporator effect
 - b) Milk inlet temperature into the first evaporator effect
 - c) Milk flow rate
 - d) Temperature in the last effect
 - e) Vacuum and stability in all evaporator effects
 - f) Dry matter content or specific gravity
- All parameters must be kept as constant as possible to achieve a uniform product quality.

In automatically operated plants, these parameters are monitored and processed in a computer. A simple signal is given by determining the specific density by weighing, as shown in Figure 9./10. After leaving the last effect of the evaporator, concentrate passes through a device, and the mass is compared with a reference. In case of deviations from the reference, the fresh steam supply into the first effect is controlled through a system of levers.

At the end of the concentrate manufacture, a material balance must be established, which requires a comparison of the theoretical amount and the actual amount of concentrate. The amount of concentrate is calculated according to the preceding formulas when the concentration ratio is known or according to the following formula:

$$m_c = m_m \cdot \frac{DM_m}{DM_c}$$

- m_c mass of concentrate in kg
 m_m mass of milk in kg
 DM_m dry matter content of milk in %
 DM_c dry matter content of concentrate in %

9.3. Evaporated milk

9.3.1. Terms

The term “evaporated milk” is used for a concentrated milk or cream without the

addition of sugar. “Sweetened condensed milk” is another product group and will be described in a separate section.

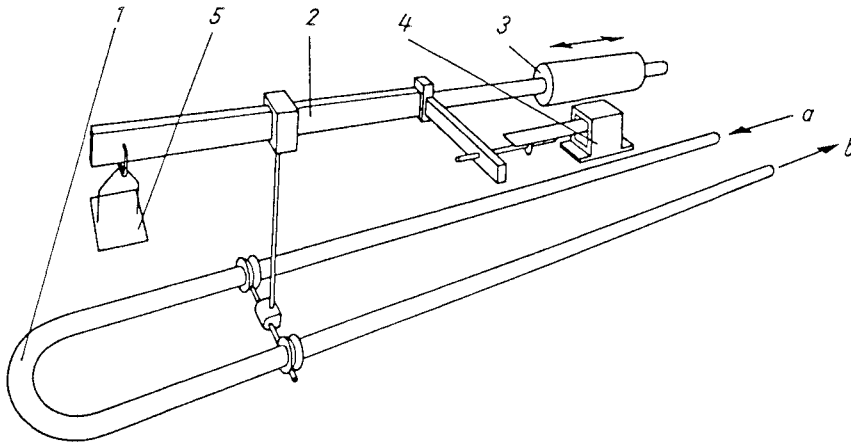


Figure 9./10 Weighing device for continuous determination of the concentrate density

a) Concentrate inlet b) Concentrate outlet

(1) U-tube (Concentrate pipeline) (2) Beam (3) Movable counterweight (4) Connection to control unit (steam valve) (5) Support for reference weight

- Evaporated milk is a product made from milk or cream, partially concentrated by evaporation, sterilized by heat treatment, which can contain up to 25% of its dry matter content in the form of milk powder and which is filled aseptically or sterilized in the container(s).

The colloquial term condensed milk is inappropriate from a technological point of view, as no condensation takes place; instead a concentration takes place by water or steam removal. In the following section the term “concentrate” is used when describing a unit operation. In English, the terms “evaporated milk,” “condensed milk,” “sweetened condensed milk” and “concentrated milk” are used for different kinds of products.

In Germany, evaporated milk is manufactured in four types with standardized dry matter and fat content:

Evaporated milk with a high fat content	$DM \geq 26.5\%$, $f \geq 15\%$
Evaporated milk (whole milk milk)	$DM \geq 25.0\%$, $f \geq 7.5\%$
Partially skimmed evaporated milk	$DM \geq 20.0\%$, $f > 1.0 < 7.5\%$
Skimmed evaporated milk	$DM \geq 20.0\%$, $f \leq 1.0\%$

Other evaporated milk products must be derived from the standard products.

9.3.2. Technology

Milk selection, pretreatment and concentration in the manufacture of evaporated milk are as described in Section 9.2. Only specific operations such as homogenization, filling and sterilization are described.

9.3.2.1. Homogenization

Homogenization of evaporated milk has the following objectives:

- a) Avoid creaming of fat in the pack, e.g., formation of a fat plug in the bottle neck (when filling into bottles) or adherence of fat to the inner wall of the pack
- b) Improvement of whitening effect in coffee
- c) Improvement of flocculation stability of protein in coffee

During homogenizing, fat globules are reduced in size and proteins are modified, which results in a viscosity increase. This phenomenon is based on a significantly increased surface of the fat globules, resulting in the formation of casein agglomerates. This viscosity increase is very noticeable at $DM > 31\%$.

As evaporated milk is used mainly as a coffee whitener, whitening power and flocculation stability are important factors. Improvement of the whitening power must be viewed in the context of the formation of casein agglomerates and a much finer fat distribution.

The same principles apply for flocculation stability as for the homogenization of sterilized coffee cream (see 5.3.3); i.e., a double-stage homogenization is optimal. The recommendation is 200 bar for the first stage and 50 bar for the second stage.

Manufacturing evaporated milk with the UHT process means a first homogenization after concentration and a second aseptic homogenization after the UHT process. When manufacturing sterilized evaporated milk, the homogenization process is done after concentration (double stage), and the same pressure conditions are applied.

9.3.2.2. Packaging

Filling of evaporated milk is controlled by the heat treatment process utilized. UHT products are filled aseptically in one-way units, as described in Section 5.1.3.3. Evaporated milk, which is sterilized in the pack, is filled into glass bottles or cans.

Bottle filling. Filling into bottles is done on similar lines as used for filling market milk, but here a closure that makes the bottle airtight is required. For this purpose, crown caps are used, which are made from metal having an inserted aluminum coated cork or from plastic. These crown caps are pressed in sealing machines. A working principle is shown in Figure 9/11.

Can filling. Normally, cans are manufactured insitu in automatic devices, where the bottom and lid are either welded or soldered. The lid still has a hole (diameter 2–3 mm). The can is placed in a carousel and the can is filled through the center hole. Thereafter the hole is soldered. In another technology, the can is manufactured together with the bottom part. The lid is applied after filling.

After filling there is a check on tightness, which is normally done in a water bath, making a product discharge visible. Checked cans are then transferred to a sterilization unit.

9.3.2.3. Sterilization

The UHT process (as described in 4.2.7.2 and 4.3.2) is a (continuous) sterilization process for milk and milk products. The requirements for absence of germs are not as high as those for in-package-sterilization.

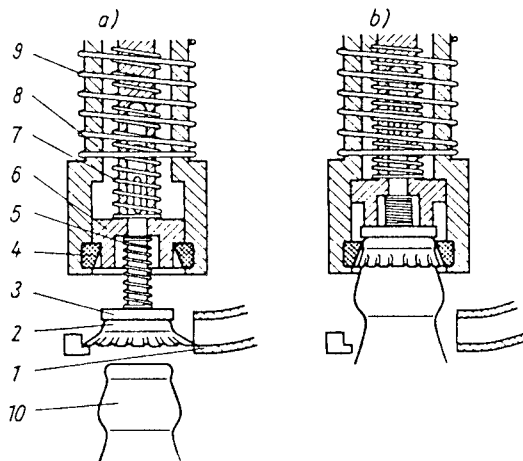


Figure 9/11 Crown cork sealing head

a) Placement of the crown cap b) Closing of the bottle

(1) Supply chute (2) Crown cap (3) Cap holding device (4) Pressing cone (5) Arresting spring (6) Pressure device (7) Pressure spring (8) Spring device (9) Compensation spring (10) Bottle

- Sterilization (inactivation, killing of all germs) is the destruction of all germs and vegetative forms of microorganisms.

Preheating of evaporated milk to temperatures far above those of pasteurization is insufficient to achieve sterility. On one hand, not all vegetative spores are inactivated, on the other hand, recontamination until filling cannot be excluded. Therefore a second heat treatment—sterilization proper—at similar high temperatures and longer times must follow.

Basics. In real life, sterilization temperatures are always above 100 °C. The required residence time is shorter when the temperature is raised (in the form of an exponential curve, see also Q factor Section 4.2.7.1), but during sterilization in the pack, significantly slower heat transfer into the product must be considered (slower compared to a flowing product in a plate or tubular heat exchanger). The following factors are decisive for the selection of the time-temperature conditions:

- Composition of the product to be sterilized
- Type of packing and dimensions
- Requirements for shelf life

- Normal time-temperature combinations are 115–120 °C for 12–20 min holding time. The sterilization temperature should not exceed 125 °C.

Figure 9/12 shows a time-temperature curve for sterilization. For practical applications, sterilization tests must be conducted to determine the optimal profile. The product to be sterilized, is mixed with specific heat-resistant and toxic test germs such as *Clostridium botulinum* and *Clostridium sporogenes* under laboratory conditions in order to determine lethality (degree of percentage of inactivated germs during the sterilization test). For this purpose samples are incubated after the sterilization for 60 h at 37 °C and are then subjected to microbiological, organoleptic (taste, flavor, coagulation) and chemical-physical (pH) analysis.

Another key parameter for the sterilization effect is the so-called F value.

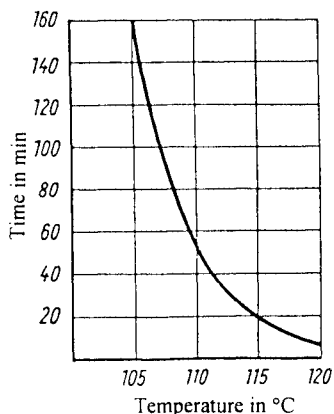


Figure 9./12 Time-temperature combination for the sterilization of evaporated milk

- The F value corresponds to the time (in minutes), that is required to inactivate the germs completely at a temperature of 121.1 °C (or 250 °F).

This means that for $F = 2$ or $F = 4$, a temperature of 121.1 °C must be available for 2 or 4 min to inactivate germs. for example, the F value for *Clostridium botulinum* is 2.52. Further, the F value can be calculated when considering other factors such as heat resistance z and destruction value D .

Sterilization equipment. As sterilization temperatures are > 100 °C and water and steam are used as a heating medium, all sterilization equipment (sterilizers) is characterized by closing tightly and being stable against a high internal pressure. There are batch retorts and continuous sterilizers.

Batch installations (retorts) (Figure 9./13). These consist of a cylindrical shell with outer insulation; loading takes place through a front door, which is movable and can be closed tight. The product is placed on a trolley or basket, which rotates around its longitudinal axis during sterilization; this trolley is then moved or pushed into the retort. After the lid has been closed tight, the retort is filled one third with water and steam is injected until the sterilization temperature has been reached. The rotation of this cage (basket) ensures a uniform heating of the product and prevents a burning-on effect.

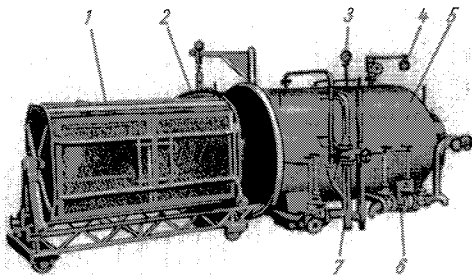


Figure 9./13 Batch retort with rotating frame (basket/cage)

(1) Frame (basket) for loading with product (rotating around its own axis) (2) Lid with special screws for closing (3) Pressure gauge (4) Safety valve (5) Double-walled shell (for heating and cooling) (6) Water inlet and outlet (7) Steam inlet

After sterilization is complete, steam is turned off and cooling water is injected until the product has reached about 20 °C (after about 15–20 min). After cooling water has been discharged, the lid is opened and the crate is taken out of the retort.

Continuous installations. These are operating on a hydrostatic principle and are based on the effect of communicating tubes. Each installation has at least two water filled columns (which are open at the top) and one closed column (between the two), which is filled with steam (sterilization chamber). During operation, there is an equilibrium between the sterilization chamber and the water columns. The height of the water column (and therefore the height of the installation) depends on the required steam temperature.

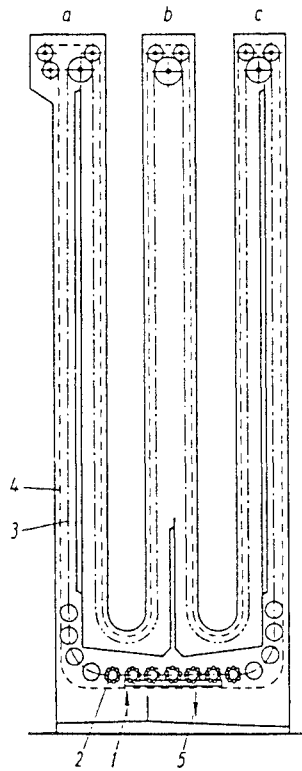


Figure 9./14 Continuous sterilizer type CAM

a) Preheating column (water) b) Sterilization column (saturated steam) c) Cooling column (water)

(1) Bottle inlet (2) Rotating bottle carrier RPM 8 (3) Endless chain for transport of bottle carrier through the installation (4) Endless chain causing rotation of bottle carrier during transport in the installation (5) Bottle outlet

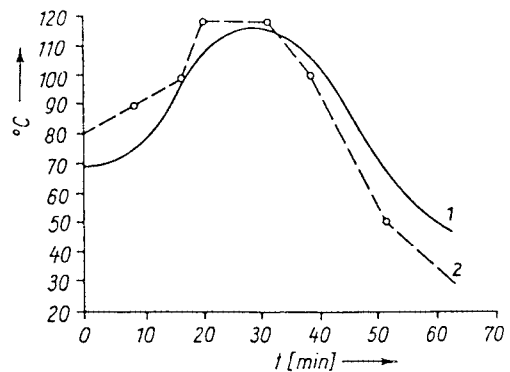


Figure 9./15 Time-temperature profile in a continuous sterilization plant

(1) Product (2) Heating and cooling medium

Task : What should be the height of the water column (w_c) of a sterilization plant if the sterilization temperature is $118\text{ }^\circ\text{C}$?

Solution $118\text{ }^\circ\text{C}$, 182.4 kPa steam pressure (see table 9./1)
 182.4 kPa , 83.3 kPa overpressure
 98.1 kPa overpressure, 10 m water column
 85.5 kPa overpressure, 8.5 m water column
 The height of the water column must be 8.5 m .

The modus operandi of the installation of Figure 9./14 is that the filled bottles (or cans) are transferred onto a carrier drum (2), and are then transferred via a endless transfer chain (3) into a tower (a), where the cans are tempered in the left column with warm air. A section of the chain causes rotation of the carrier support, thus accelerating and making the heat transfer uniform.

In the upper part of the tower (a), cans are immersed in a preheating column, and at the bottom outlet they have a temperature of about 90 °C. Then they are transferred into sterilization column (b), where they are subjected to a fixed time-temperature profile. After leaving the sterilization section, the product enters the water column of the cooling zone (c) and leaves the upper part of the tower with a temperature of 55 °C.

The water columns of sections (a) and (c) are linked by pipelines, so that temperatures at the bottle inlet do not decrease too much, and temperatures at the bottle outlet does not rise too much. Bottles are discharged in the bottom section of tower (c) (5). Low-viscosity products such as sterilized milk or coffee creamer do not require rotation of the support carrier, as there is a sufficient heat transfer without rotation.

If required, an additional cooling section (column) can be attached, independent of the tower (c), where the product is cooled to a temperature of 30–35 °C.

Total residence time in the tower is about 1 hour, subject to the selected sterilization time. Figure 9./15 shows the temperature profile of a product heating and cooling medium in a continuous sterilizer. These installations are made for capacities of 3–12,000 liter bottles per hour. For smaller bottles, the bottle capacity is increased accordingly.

9.4. Sweetened condensed milk

9.4.1. Terms

- Sweetened condensed milk is a product made from milk or cream, concentrated partially by evaporation, and preserved by the addition of saccharose, sometimes up to 25% milk powder and/or lactose (up to 0.02% of dry matter) is added.

Standard products with defined total dry matter (*DM*) and fat contents (*f*) are:

Sweetened condensed milk (whole milk)	$DM \geq 28.0\%, f \geq 8.0\%$
Sweetened condensed milk (partially skimmed)	$DM \geq 42.0\%, f > 1.0 < 8.0\%$
Sweetened condensed milk (skim milk)	$DM \geq 24.0\%, f \geq 1.08\%$

Sweetened condensed milk not only is used as a coffee whitener, but also is consumed as such due to its sweet taste, especially by children. Sweetened condensed milk is used as an energy concentrate in sports and for hiking.

9.4.2. Technology

Manufacture consists of the basic unit operations milk selection and pretreatment, concentration and sugar addition, cooling of the concentrate and filling.

For milk selection and pretreatment, the statements made in Section 9.2.1 are valid. Of special importance is preheating, by which all the harmful germs are inactivated and protein is stabilized. There is no sterilization of this products (such as in evaporated milk). Growth of the remaining germs is inhibited by the high sugar concentration.

9.4.2.1. Condensation and crystallization

Concentrate is manufactured in the same way as evaporated milk; however, during concentration, a highly concentrated sugar solution must be blended with the product in the evaporator. Therefore installations such as a recirculating evaporator (batch process) are used.

Sugar addition. The sugar/water concentration $C_{S/W}$ or sugar ratio is very important for inhibiting the growth of microorganisms and therefore for the minimum shelf life. The sugar ratio should be in the range of 60–64%, the saccharose content S should be $\geq 40\%$, and the moisture content should be $\leq 27\%$. The sugar/water concentration is calculated as

$$C_{S/W} = \frac{S}{S + W} \cdot 100\%$$

Task: What is the sugar/water concentration in sweetened condensed milk if a saccharose level of 45% and a moisture content of 26% have been analyzed?

Solution

$$C_{S/W} = \frac{45.0\%}{45.0 + 26.0} \cdot 100\% = 63.4\%$$

The sugar/water concentration is 63.4%.

Saccharose addition to base milk is determined as the quotient of the sugar/water concentration over concentration degree c (see 9.2.1 and 9.2.2.4).

$$S_m = \frac{C_{S/W}}{c}$$

For this model calculation we use a sugar/water concentration of 63.4% and assume a concentration degree of 2.35. Saccharose addition to base milk is therefore

$$S_m = \frac{63.4\%}{2.35} \approx 27\%$$

Different types of saccharose can be added subject to quality requirements of the finished product.

A sugar solution is prepared in a heated vessel with a stirrer, by batchwise dissolution of sugar in water or skim milk (based on calculated quantities); skim milk is always a worse solvent than water. Then the sugar solution passes through a sieve (for retention of nondissolved sugar) and is then transferred into an evaporator. Evaporation of the milk/sugar solution must be controlled by regulating vacuum and heat in such a way that there is no lactose crystallization during this operation; otherwise product defects such as a “sandy texture” can develop. The tendency for crystallization of lactose is favored when the readily soluble saccharose binds additional water. This is mainly the case when there are still some undissolved saccharose crystals. Another cause can be too rapid movement of the product in the evaporator, leading to premature lactose crystallization.

Evaporation is assumed to be finished when the product has reached the desired concentration. This can be determined easily by the density, or as done very often with the Baumé hydrometer (see table 9./2).

- As a guideline, the finished concentrate at 49 °C should have 32 Bé and at 15 °C it should have 33.5 Bé, corresponding to a density of 1.30 g/ml at 15 °C.

As can be seen in Figure 9./16, at 10 °C there is a 13.1% lactose solution (5% α -lactose, 8.1% β -lactose; see also 2.3.4.1); at 40 °C, however, there is a 25% lactose solution. This temperature relationship for lactose solutions is the main reason for the lactose crystallization. Assuming that for an evaporation temperature of 60 °C there is a saturated solution, supersaturation would occur during the cooling phase, and crystallization would take place. This is enhanced by the fact that saccharose uses part of the solvent and when there are already some lactose nuclei in the concentrate this promotes crystallization. Crystallization can start in the range between final solubility and supersaturation, i.e., the metastable range. Lactose crystallizes only until saturation has been reestablished.

9.4.2.2. Cooling and filling

Immediately after concentration, sweetened condensed milk must be cooled; here the aspect of lactose crystallization reappears. As this crystallization cannot be avoided entirely, the process must be controlled in such a way that there is a very fine crystalline structure. For lactose there are three phases of dissolution (Figure 9./16):

- Initial solubility
- Final solubility or saturation
- Supersaturation

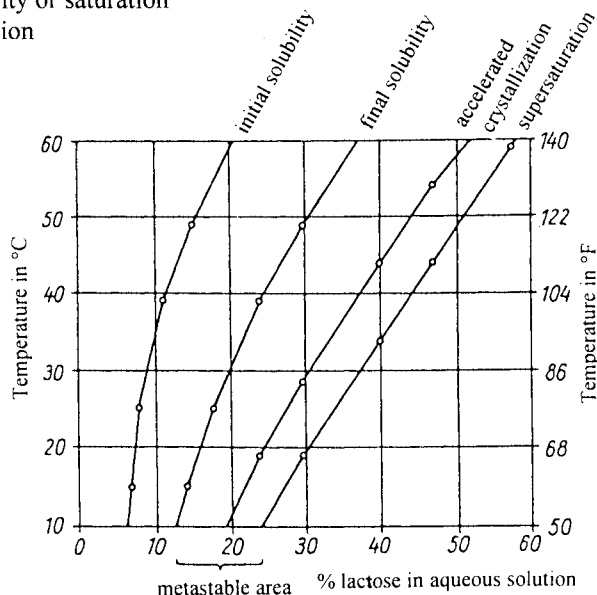


Figure 9./16 Solubility curves of lactose in water

During lactose crystallization, which cannot be excluded, crystal diameters of < 15 μm are targeted. With diameters of 18–30 μm , a “floury” texture and with diameters > 30 μm a sandy texture will be noticeable. The following actions reduce the unavoidable crystallization:

- Rapid cooling of the concentrate to an optimal crystallization temperature of 20–30 °C
- Inoculation with crystal nuclei by adding finely milled and pulverized lactose (about 125 g) after cooling to crystallization temperature
- Constant slow stirring of the product (too strong mechanical stress inhibits crystal formation)

The cooling process takes about 60–90 min (as a function of the cooler), until a final temperature of 14 °C is reached. This temperature prevents further noncontrolled crystallization which would occur at lower temperatures.

Cooler. A well-known shape is the vat cooler (Figure 9./17), a cylindrical double-walled vessel in which stirrers rotate and swing. Vat coolers are suitable for batches of 500 kg. For larger capacities, evaporative coolers are used, which are constructed as vacuum vessels. By lowering the pressure, the condensed milk is kept at its boiling point.

- Pressure is continuously lowered to 1.5–1.9 kPa, corresponding to a temperature of 15–17 °C.

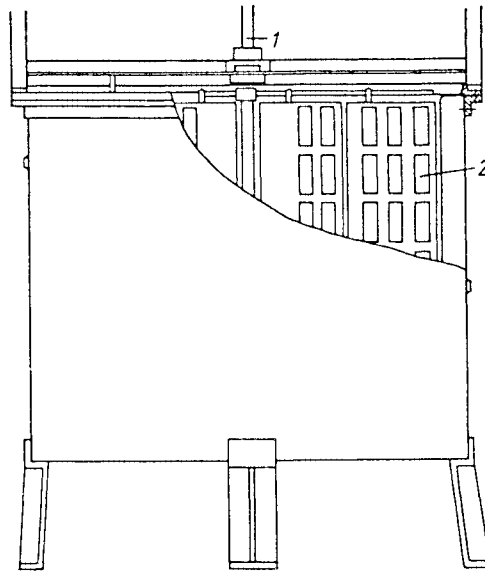


Figure 9./17 Vat cooler system Saliter

(1) Drive (2) Stirrer

As no exterior heat is supplied to the process, the product requires its own enthalpy for evaporation (2260 kJ per kg evaporated water at 981 mbar) and therefore cools slowly. Lactose crystallization can be further optimized by automatic control of the cooling process.

Filling. Filling of sweetened condensed milk is done immediately after cooling and is done mainly into tins, sometimes wide-mouth jars or plastic packs of different sizes are also used. The packs are designed as one-way packs.

9.5. Milk powder

9.5.1. Terms and categories

- Dried milk (milk powder) is a dehydrated product made from dairy-processed milk or cream by removing water in evaporators and drying; it has a moisture content of $\leq 5\%$.
- Dried milk products are made from milk, cream or dairy-based raw materials in a similar way as dried milk and have a moisture content of $< 5\%$. Sometimes approved preservatives (ascorbic acid), lactose products to a maximum of 32% of the product, and of lactase (added for drinks) are added.

In addition dried milk products can contain other additives, if permitted by legislation. To maintain and improve flowability, aluminum silicate or calcium phosphate may be added up to 1.0%; to improve solubility in water, especially for vending machine beverages, sodium and potassium orthophosphate up to 0.15%; and as an emulsifier for fat containing products lecithin (up to a level of 0.5%).

Further, dried milk preparations are manufactured as blends of milk powder and/or dried milk products with other foods, where the percentage of milk dry matter must be at least 51%.

Categories. The classification of the products is based on raw materials, from which products such as milk powder, yogurt powder, kefir powder, buttermilk powder are derived. It may also be based on the fat content f . We distinguish between

Cream powder	$f \geq 42.0\%$
Milk powder (whole milk)	$f \geq 26.2\%$
Milk powder (partially skimmed)	$f > 1.5\% < 26\%$
Skim milk powder	$f \leq 1.0\%$

Buttermilk powder should have a maximum moisture content of 7.0% and a maximum fat content of 15.0%.

According to the FAO/WHO standards ("Code of Principles"), classification is based on the fat content f :

Whole milk powder	$f \geq 26\%$
Skim milk powder	$f \leq 15\%$
Cream powder such as	
High fat milk powder	$f \geq 40\%$
Cream powder	$f \leq 65\%$

The highest production volume is seen for skim milk powder because of its good storage characteristics and its multiple applications in food and feed production. Whole milk powder is utilized mainly in the manufacture of baby food or for reconstituted market milk.

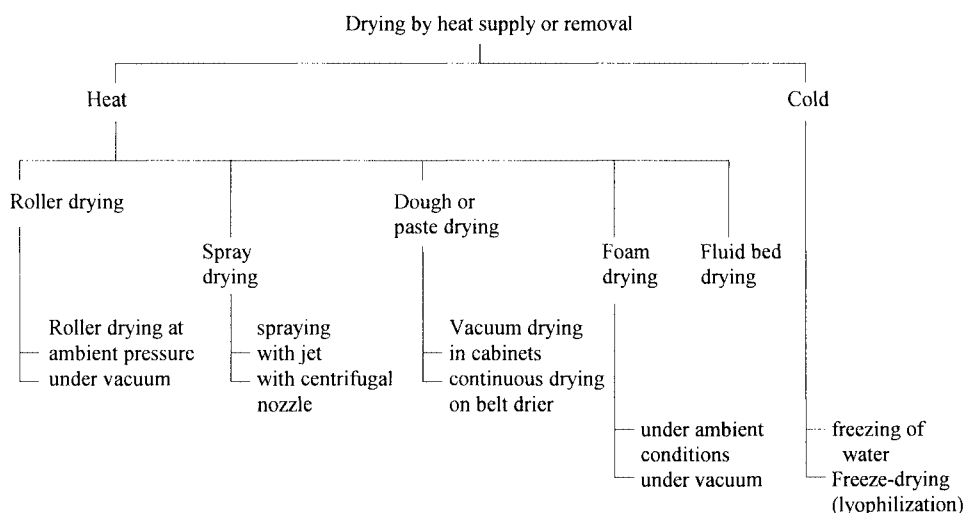
Other dried milk products are manufactured for specific applications, such as cream powder for coffee whitener, dietetic products, milk protein powders and demineralized whey powder from milk concentrates or milk products, which are manufactured by ultrafiltration, reverse osmosis or electrodialysis. Whey powder is manufactured on a large

scale, as described in Chapter 10. Cream powder with a fat content of 70–80% is also labeled butter powder, as it results in a butter-like product when dissolved in water.

9.5.2. Technology

The manufacturing process consists of the unit operations of milk selection and pre-treatment, concentrate manufacture, homogenization, drying and filling/packing. The basic difference is in the type of drying, and Overview 9./2 shows the different possibilities in the dairy industry. Actually, we mostly encounter drum drying (contact drying, film drying) and spray drying. Other types of drying such as fluid bed drying are used in combination with the major types of drying.

Overview 9./2 Possible drying technologies in the dairy industry



The selection of the technology is mainly governed by factors such as utilization of the product or powder and economic aspects. Another key factor is the space requirements of the installations, which can be quite different.

9.5.2.1. Milk selection and pretreatment

Milk is selected according to requirements described in 9.2.1. Clarification and standardization are done in the same way.

Heat treatment. Base milk or milk products must be heat treated by an officially approved pasteurization process in order to inactivate possible pathogenic or other harmful germs and to inactivate most of the enzymes. Another intensive preheating, such as is normal for evaporated milk, is not required here, because the recontaminating germs cannot grow at the moisture levels available in the powders, and protein stabilization is not necessary. On the contrary, very gentle pasteurization is required in order to have the least whey protein denaturation.

Among other factors, the quality of skim milk powder is measured by the non-denatured whey-protein-nitrogen index (WPN index), which characterizes the heat treatment involved. From this heat classification the application or utilization of the powder can be derived (see also Overview 9./3). For certain applications, e.g., baby food (infant for-

mula), the classification of the gently heated proteins by the WPN is not sufficient, and other criteria such as the protein number (ratio of casein nitrogen and whey protein nitrogen vs. total protein nitrogen), organoleptic evaluation of the reconstituted milk or the coagulation and acidification capability (e.g., for cheese manufacture) must be taken into consideration.

- For the manufacture of “low-heat” skim milk powder, the short-time heat treatment must be used; for “high-heat” skim milk powder, the process temperature is 90 °C for 30 minimum.
- For the production of whole milk powder, base milk is heated to 90–95 °C and held for 15–30 s, which is considered optimal.

Whole milk powder cannot be manufactured in a low-heat quality, as lipases would be inactivated insufficiently and fat oxidation and a significantly reduced shelf life would occur.

Overview 9./3 Skim milk powder with different heat treatment processes

Nondenatured whey protein nitrogen in mg per g powder	Application	Designation according to American Dry Milk Institute
6.0 and more “low-heat powder”	Instant milk powder for reconstitution and recombination of market milk, cheese milk, milk for baby food products (infant formula), milk for acidified milk products coffee whitener	Low Heat
1.51–5.99 “medium-heat powder”	For various applications in the food industry, e.g., in the bakery industry, also in meat processing	Medium Heat
1.5 and less “high-heat powder”		High Heat

Homogenization. To improve the fat distribution, homogenization is advantageous during the manufacture of whole milk powder. If base milk is fat-standardized by adding cream, partial-flow homogenization (see Section 4.2.4) is possible before concentration. Otherwise the concentrate is homogenized.

9.5.2.2. Concentration

The objective of concentration is to remove a maximum amount of water from the milk and obtain a maximum dry matter content, as the drying process requires three times more energy than the removal of water in the evaporator.

- The milk is concentrated to its flow limits, i.e., dry matter will be 40–50%.

The concentration ratio selected is controlled by the finished product and the drying process; the ratios are as follows:

Drum-dried whole milk powder	1 : 3.5–4
Drum-dried skim milk powder	1 : 4–6
Spray-dried whole milk powder	1 : 3.5
Spray-dried skim milk powder	1 : 4–5

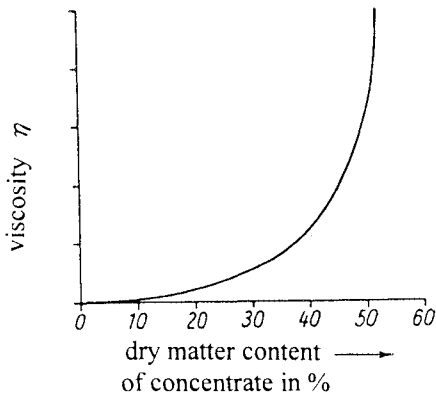


Figure 9.18
Effective viscosity as a function of the dry matter content of the milk concentrate

A further increase of the concentration ratio in the evaporator is characterized by a significant increase in viscosity (Figure 9.18) and is very difficult due to the flow limits of the concentrate.

Evaporator installations. For manufacturing a concentrate for drying the same types of installations are used as for evaporated milk; in most cases they are multieffect falling film evaporators, in a few cases double-effect recirculation evaporators.

9.5.2.3. Drying

- Drying is the separation of a liquid from a compound or blend of compounds by evaporation. The product to be dried exists either in a solid or solid-liquid phase. The separation is into a solid and a gas phase.

Drying of a concentrate into a milk powder is done mainly by spray drying.

- Evaporation is the removal of a liquid from a material (product to be dried), where the saturated steam pressure on the surface of the product to be dried is lower than ambient pressure. Air flowing over the product surface transfers its enthalpy to the product and absorbs the product's moisture.

In this case product moisture does not have to reach the ambient pressure; therefore the product is not heated to the boiling point. This means that there are different temperatures between the two phases which are in contact with each other. A temperature differential always goes from the gaseous phase to the product to be dried.

9.5.2.3.1. Roller drying (drum drying)

The product to be dried is applied in a thin layer (film) onto the surface of one or two steam heated drums by using different application systems. The temperature on the drum surface is above 100 °C, and heat can be transferred rapidly to the product. This helps in transferring moisture that is evaporated to the ambient air and removing it by an airflow.

After a three-quarter turn of the drum, the drying process is finished, and the film is removed from the drum by special knives (doctor blades) as a thin film, air-cooled, and milled into powder in a special mill. After intermediate storage in silos the powder is filled and packed.

Design and operation of some drum dryers

Monocylinder with applicator drums (Figure 9./19). From the evaporator, concentrate reaches the product trough (3), is picked up by the concentrate drum (4), and is transferred to the applicator drum (5), which then delivers the concentrate to the surface of the drying drum (1) (made from cast iron). The drum is steam heated from the inside and has a surface temperature of 115–130 °C, and rotates at 10–30 RPM, which corresponds to a peripheral velocity of 1.5 m/s. Ambient air flows over the surface of the drum, is mixed with vapor, and is sucked through the vapor hood to the outside. The process is controlled by the film thickness by adjusting the applicator drum and drum speed.

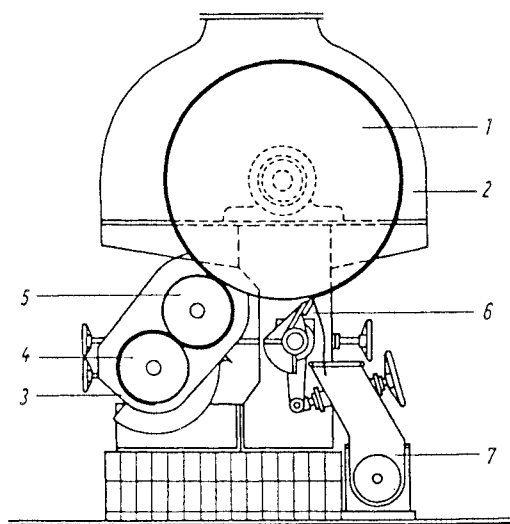


Figure 9./19 Thin film single drum drier system Büttner

(1) Main drying drum (2) Vapor hood (3) Concentrate trough (4) Concentrate drum (5) Applicator drum (6) Dried milk removal (7) Dried milk screw conveyor

Double drum drier with spraying device (Figures 9./20 and 9./21). The drying process is similar to the one shown for the drum in Figure 9./19; only the product application is designed differently. Small spraying disks (4) rotate in the concentrate trough (5), and transfer a thin concentrate film to the vicinity of the air nozzles (3). The adhering concentrate is removed from the disks by air flow and is sprayed onto the drying drum (2) in the form of small droplets. This results in another increase of the surface of the product, and gentle and rapid drying is achieved.

Another major effect is the Leidenfrost phenomenon; at the moment of impact on the hot drum, a steam layer of low heat conductivity forms around the droplet, which permits to “floating” the droplet for a short time. This delayed moisture removal at the beginning of the drying process results in gentle product treatment with a lower thermal stress.

Other types of drum dryers have application devices where the product is sprayed through jet nozzles, but there is always a risk of a blockage of the ports.

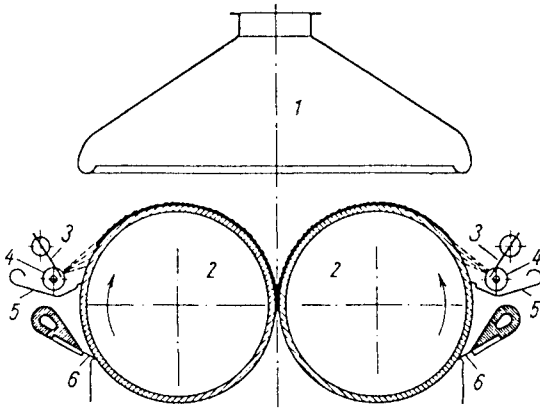


Figure 9./20 Double drum drier system Escher-Wyss

(1) Vapor hood (2) Drying drums (3) Air nozzles (4) Spraying disks (5) Concentrate trough (6) Doctor knife

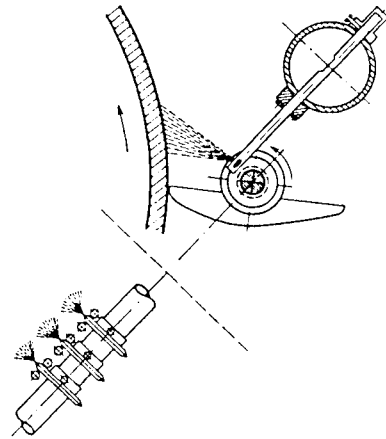


Figure 9./21 Spraying device for double drum drier of Figure 9./20

Double drum drier with sump (Figure 9./22). The key difference is the sump (2) between the two drum (1), resulting in direct application of the product onto the drum surface. Doctor knives (3) remove the dried product as a film from the drum surface; in some cases the product is cooled on cooling drums before being milled.

As the product layers are thicker with this type of drum drier, the product quality is not the same as with other dryers, however the capacity is significantly higher. This type of drier is also suitable for non-concentrated products such as e.g. acidified milk products.

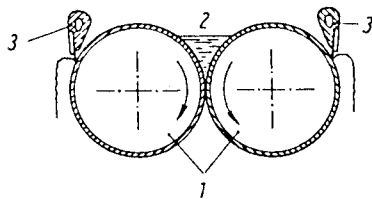


Figure 9./22 Double drum drier with sump

(1) Double drums (2) Sump (3) Doctor knives

Control of drying, ratios and capacities. Drum drying is influenced by the following factors:

- a) Thickness of the film
- b) Uniformity of the film
- c) Drying temperature and time, controlled by steam pressure, speed or drum velocity
- d) Concentrate temperature and dry matter content or concentration ratio

In order to achieve constant operation and therefore constant product quality, all parameters must be kept constant during the start-up phase, and only one or two factors should be modified. Operational control is mostly achieved with the drying temperature (steam supply) and/or drum speed with the objective of an optimal drying time.

- The drying time should be kept within 1.8–2.5 s.

This ensures gentle product treatment with low denaturation of the nutrients, mainly the proteins, and it also avoids burning on the drum surface, which impairs normal operation.

A key operational figure for evaluating the manufacturing process is the steam consumption.

- The specific steam consumption is 1.3–1.6 kg per kg of evaporated water and is 4.3–5.0 kg per kg powder.

Before starting the process, the drums must be preheated to operating temperature, which makes it possible to profit from the Leidenfrost phenomenon from the beginning. Evaporator capacity and drying capacity are coordinated with each other in the processing lines, thus eliminating longer intermediate storage between evaporation and drying and ensuring a continuous operation. This avoids heat losses and acidification.

Depending on the size and type of drums, the drying capacity of drum dryers is in the neighborhood of 300–2000 l of concentrate per hour with a dry matter content of 45%. Other factors that affect the capacity are:

- a) Concentration ratio or dry matter content of the concentrate
- b) Viscosity of the concentrate
- c) Acidity of the concentrate (with an increase of the SH value from 7.5 to 8.0, the capacity can be reduced by 10%)
- d) Steam pressure, i.e., surface temperature of the drum (too high a temperature reduces the capacity due to burning of the product on the drum, too low a temperature causes too slow water removal)

9.5.2.3.2. Spray drying

Spray drying requires an extensive and costly installation, but makes it possible to manufacture powder qualities for different applications and quality standards.

Drying principles and operation. Spray drying is based on the principle that a product is sprayed into a chamber—filled with circulating hot air—in the form of small droplets, thus increasing the surface and permitting rapid mass transfer (heat and moisture). When spraying 1 liter of liquid, droplets are formed having a surface of 120 m², basically all with the same diameter.

These droplets are picked by the hot air and circulated, and thus absorb the heat that is required for evaporation. The evaporated moisture is absorbed by the air and removed. The dried powder particles fall to the bottom and are then removed. Exhaust air is removed on the side and passes through cyclones and filters (where entrained powder particles are separated and recovered).

The hot air inlet temperature is 170–250 °C, and product temperatures are < 100 °C. With these temperature differences, rapid heat transfer and therefore rapid and gentle drying is achieved. However, heat denaturation in the product cannot be excluded, especially when the temperature profile is kept at these levels until the product's final moisture is achieved. In order to minimize degradation of sensitive products such as milk, infant formula or whey products, the drying process can be done in several stages having different time-temperature profiles in different installations. The first processing stage is done in the drying tower (see Figures 9./23 and 9./29), and the second processing (postdrying) is done in a fluid bed drying installations after the tower (see Figure 9./27).

In the second stage, so-called post- or secondary drying, a product layer with a defined height is formed in a fluid bed, through which hot air (temperature lower than the tower hot air) passes. A fluid bed is formed by the product agglomerates and vibration, thus further increasing moisture removal and stabilizing the agglomerates. In certain cases, a section is installed where no air passes through the product for control of certain reactions in the product (e.g., lactose crystallization in whey powder).

In the third and final drying zone, the final moisture of the product is achieved in a gentle way by passage of hot air with temperatures < 100 °C. In the following cooling section, the product is cooled to the designed storage, filling or transport temperature by passage of dehumidified cold air through the product. By selecting suitably sized sieves during postdrying, fine powder particles (dust) are removed and added back into the agglomeration process (during the postdrying process). At the same time different sizes of agglomerates can be separated, thus manufacturing powders of different particle sizes and characteristics.

Design and operation of drying installations. Drying installations consist of the following key components:

- a) Drying tower
- b) Hot air generation and transfer
- c) Product transfer
- d) Product and exhaust air removal
- e) Postdrying installations
- f) Sensors and controlling devices
- g) Cleaning and disinfection systems

Drying tower. A drying tower is basically a cylinder with a conical shape at the bottom, has a height of up to 15 m and a diameter of several meters. It is made from stainless steel and is insulated for energy conservation. Depending on the drying medium and product, different flow principles such as concurrent, mixed and countercurrent flow are used (Figure 9./23).

Hot air generation and transfer. The drying medium air is sucked in mostly from the production area by a fan, heated to the required product temperature by an indirect steam heating system ($p_{\text{steam}} = 8\text{--}12$ bar), and then transferred to the tower after passing through several filters. For heat recovery reasons (20–25%) a preheater can be installed before the air heating device and operated with exhaust air.

Product transfer. The product to be dried—mostly concentrate—is transferred by a pump from a balance tank to the spraying unit (two different types are usually used, jet spray nozzle and centrifugal spray nozzle). In the design of jet spray nozzle we distinguish between a single-component jet and dual-component jet nozzle. In the single-component jet spray nozzle (Figure 9./24) the product is pushed through the jet nozzle at high pressures (obtained from a high pressure pump) and is sprayed. In the dual-component jet nozzle, spraying is done by means of compressed air (Figure 9./25).

Milk spray drying is most often done with a centrifugal spraying device (Figure 9./26). A spraying disk is driven by a motor and driving belts, reaching speeds of five to seven times the speed of the motor when using a gearbox. Product is transferred via a tube into the spraying disk and is sprayed through the nozzles into the tower by the centrifugal forces.

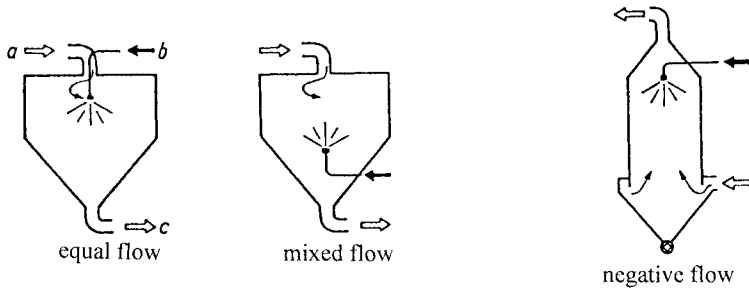


Figure 9./23 Flow patterns of drying medium and product in a spray drier

a) Drying medium b) product c) Exhaust air and dried product

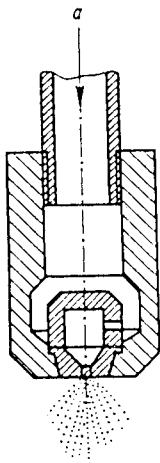


Figure 9./24 Single component jet nozzle

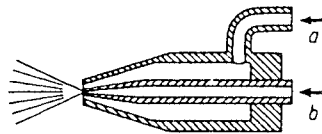


Figure 9./25 Dual component jet nozzle

a) Air inlet b) Product inlet

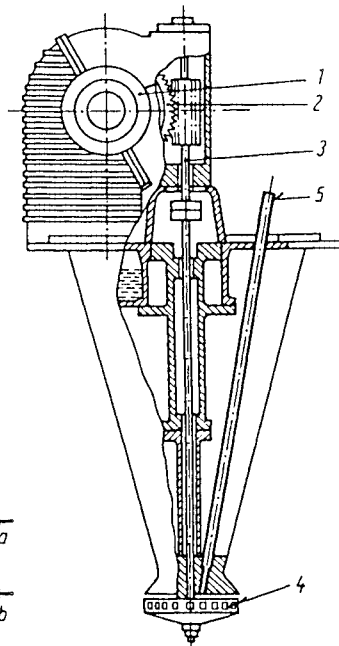


Figure 9./26 Centrifugal spraying device

(1) Driving belt disk (2) Worm wheel (3) Vertical shaft (4) Spraying wheel or disk (5) Product inlet

Product and exhaust air removal. To move the product from the bottom of the tower to the discharge openings, transport devices of different types are installed in a tower.

- a) Air blowing device—an air pipe rotates along the inside of the tower and blows product from the wall to the bottom.
- b) Hammering device—hammers bang on the outside of the tower in predetermined intervals, so that adhering powder is falling off.
- c) Bottom scraping device—a rotating scraping device transfers powder to the discharge openings.

Product transfer devices are usually pipeline systems in which the product is transported by means of compressed air. Sometimes transport screws or belt conveyors are used. In order to accelerate the transfer of powder into the transport system, vibration transport devices are used (inclined flow devices, that transfer the product by vibration).

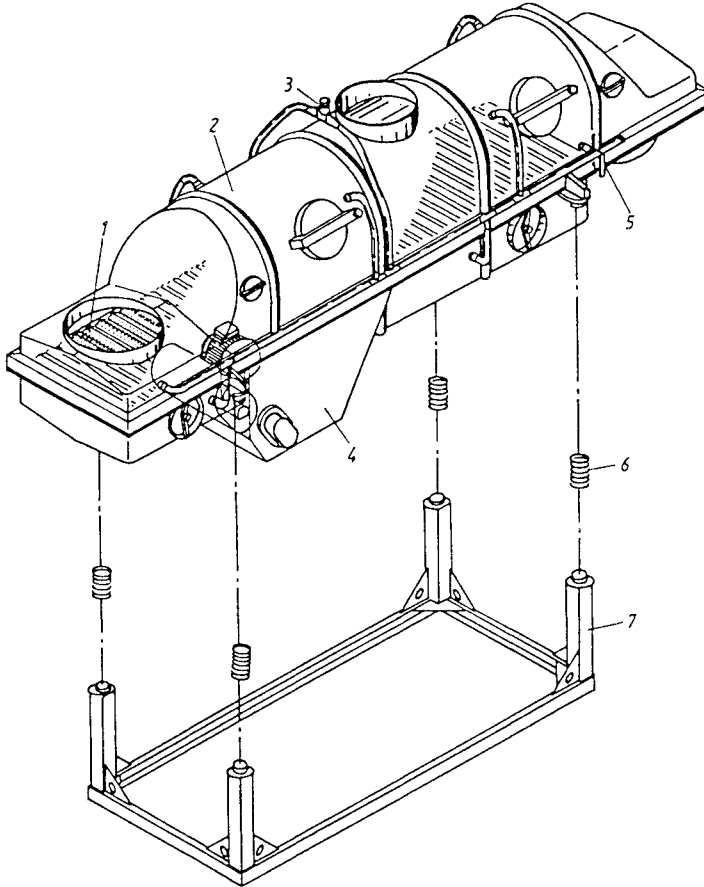


Figure 9./27 Vibrating fluidized bed, type “Vibro Fluidizer” for postdrying and instantizing

(1) Perforated sheet (sieve) (2) Housing (3) Cleaning system for CIP (4) Vibrator with drive (5) Adjustable weir (6) Spring support (7) Frame

Exhaust air is removed in large-diameter pipeline systems with fans. For dust separation, several in-line cyclones are used, based on the principle of centrifugal separation (Figure 10./1). They consist mainly of a cylinder with a conical bottom, having an inlet and outlet for air. Filters are also used for dust separation.

Unlike the drying tower, the pipeline system of the transport installation and the cyclones are not insulated.

Postdrying installations. In order to achieve a defined product quality, powder is passed through a vibrating fluidized bed drier, which reduces the moisture of predried powder from up to 20% to 1–2% final moisture. At the same time, blending, agglomeration and instantizing processes can be done by spraying a liquid component, thus obtaining a coating of the powder particles (e.g., with flavors for flavoring a product or lecithin addition for improvement of the solubility—lecithination). The particle size of the obtained

agglomerate can vary from 45 μm to 14 000 μm . Figure 9./27 shows a postdrying installation for instantizing milk powder.

Sensors and control devices. Modern drying installations are controlled and operated in an automatic or semiautomatic mode, using process controllers. This permits high operational safety, economy and stable product quality. Key parameters include temperature, pressure, flow rates, pH value, electrical conductivity and product moisture.

Cleaning and disinfection systems. Like evaporation installations, drying installations are equipped with a circulating cleaning and disinfection system (CIP), which covers all areas in contact with the product. For this purpose, insertable jet nozzles are installed in many areas from which the cleaning solution is sprayed, and these nozzles are removed after the cleaning process. Spray nozzles are rotated by the liquid pressure. Figure 9./28 shows the CIP system of such a drying installation.

Operation of a drying installation. Product (or concentrate) is transferred by a pump (2) from a balance tank (1) or directly from the evaporator to the spraying nozzle (3) at a temperature of 40–60 °C. The disk of the centrifugal spraying device rotates at 15–20,000 RPM (at an angular velocity of 120–150 m/s and sprays the product into the tower (4). Located on top of the spraying nozzle, hot air of 170–200 °C is pushed into the tower via an air distributor (5).

The powder drops to the bottom of the tower and is transferred by a vibrating device (9) into a pneumatic transport (10). A fan sucks the moisture-laden air from the bottom of the tower via a pipe (11) to the cyclone (12) to separating the powdered particles and then goes outside. The separated powders passes from the cyclone through a rotary valve (a special transport device for powdered products) into a pneumatic transport pipeline. A fan sucks the transport air through a filter (16) from the outside, which cools the powder during transport. The pneumatic transport again passes through a cyclone (15), where the powder is separated, and exhaust air is returned to the pipeline between the tower and the first cyclone. Powder is collected in a container, passes through a rotary valve and is then filled or stored in a silo. This plant can also be operated with a post-drying installation, which would be installed after the vibration transport.

Characteristics of the sprayed powder. Each sprayed liquid droplet results in a powder particle, and the basic rule is:

- Small liquid droplet → small powdered particle → rapid and gentle drying

The objective is to spray the product into the smallest possible droplets; however, this results in a very fine powder. Very small particle sizes result in a very high percentage of dust, which has the following effects:

- a) Bad solubility in water
- b) Rapid agglomeration of the powder with increased humidity
- c) High percentage of powder in the exhaust air
- d) High density (weight for 1000 ml) and bad flowability

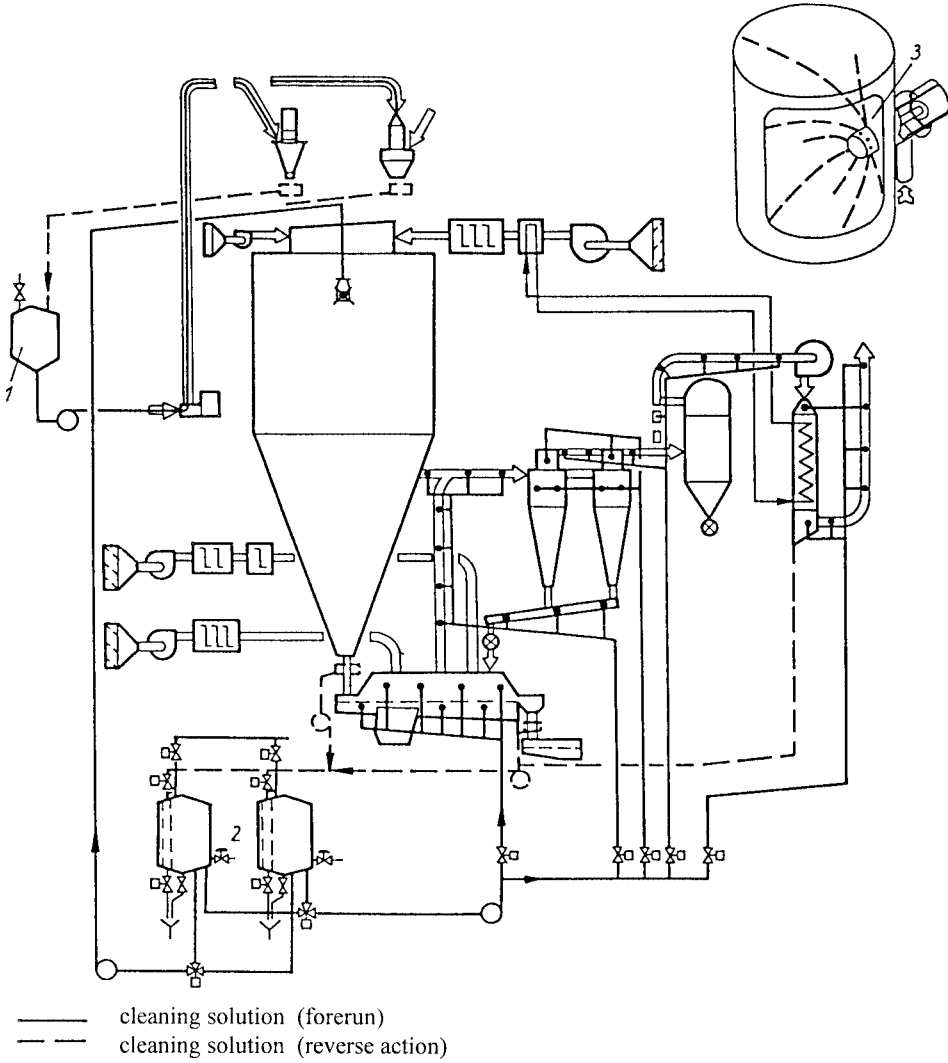


Figure 9./28 Cleaning and disinfection system of a drying installation

(1) Tank for cleaning solution for circuit "nozzle cleaning"(2) Tank for cleaning solution for circuit "Total" (3) insertable nozzles

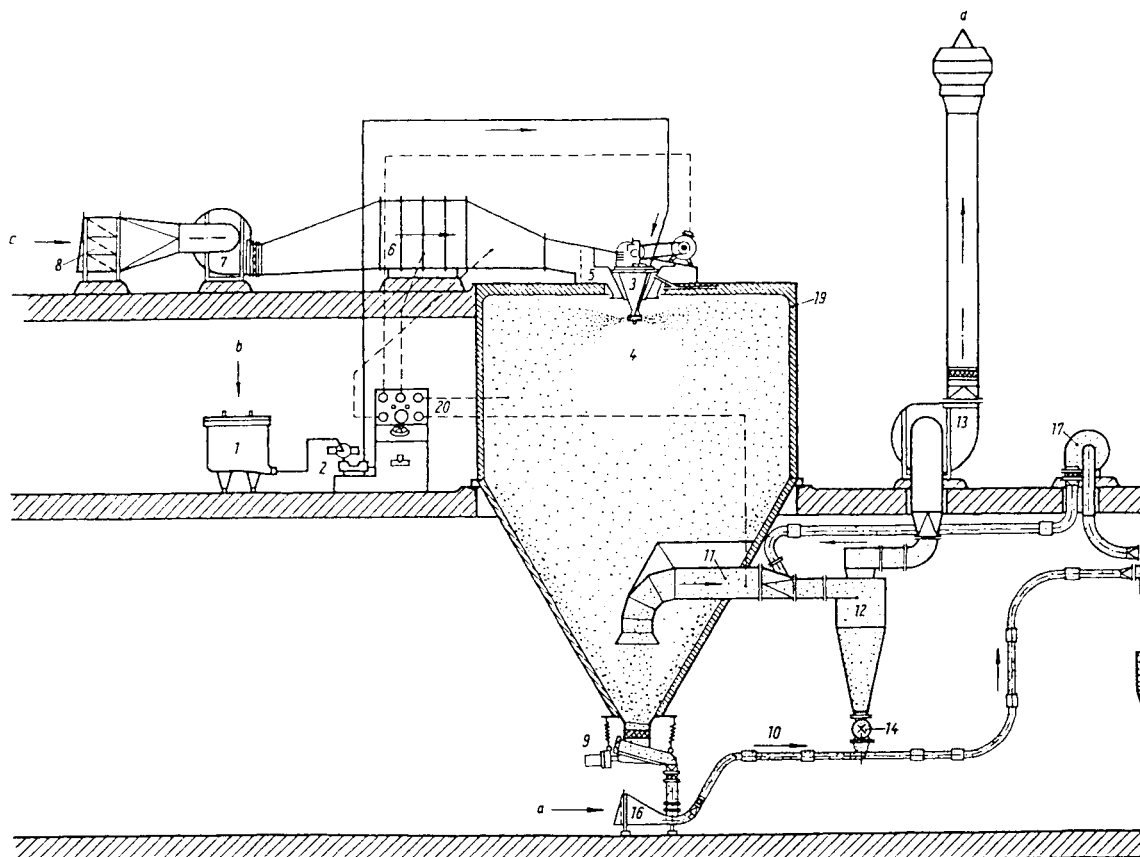


Figure 9./29 Scheme of a milk drying installation

a) Inlet of transport air b) Inlet for product to be dried c) Inlet of hot air from drying d) Exhaust air
e) Outlet for dried product

(1) Balance tank (2) Pump (3) Spraying device (4) Drying tower (5) Air distributor (6) Air heater
(7) Fan (8) Filter for drying air (9) Vibration transport (10) Pneumatic transport (11) Exhaust air
from tower (12) First cyclone (13) Fan (14) Rotary valve (15) Second cyclone (16) Filter for transport
air (17) Fan for transport air (18) Collecting container (19) Insulation (20) Control panel

In order to achieve rapid and gentle drying and have good solubility especially for high-quality products, controlled agglomeration of the powder is done in the postdrying installation. This achieves the desired instant¹ characteristics in many cases. These properties can be characterized by the solubility index, which indicates the percentage of dissolved product in the total product. During the solubilization of powder the following phenomena can be observed:

- a) Penetration of liquid into the powder floating on the surface of the liquid
- b) Sinking of agglomerates into the liquid with further rehydration of the powder
- c) Dissolution of agglomerates
- d) Partial solution of components/nutrients

Solubility and flowability of the powder are closely related. Powders with good flowability can be rehydrated more easily, which is advantageous especially for vending machines. Apart from the additives mentioned in Section 9.5.1 such as aluminum silicate and calcium phosphate, crystalline sugar or crystalline calcium lactate can be added to sticky and hygroscopic dried milk products.

Fat-containing products. Whole milk powder or fat-containing calf-rearing feed have a reduced flowability and solubility characteristics because of the percentage of free fat, which inhibits a good rehydration effect. This is valid especially for powders after longer storage periods, where free fat apparently migrates to the surface of the particle and impedes rehydration with water.

By adding emulsifiers such as lecithin, this negative effects can be avoided, and the solubility of skim milk powder can be obtained. It should be mentioned that in some countries adding lecithin to milk powder, destined for human consumption, is not permitted.

Control of drying. During the operation of a spray drier the following key factors have major significance:

- a) Quantity of hot air for drying
- b) Temperature of the concentrate
- c) Amount of concentrate to be dried

As stated in the section for roller drying, these parameters must be kept constant as much as possible in order to control one of the variable factors. The amount of hot air shows the least variation. It can be controlled by flaps in the ingoing air ducts. Air temperature and flow rate of the concentrate have a large influence and can easily be controlled automatically.

A material balance at the end of drying is done as per the equation:

$$m_p = m_m \cdot \frac{DM_m}{DM_p}$$

m_p amount of powder in kg	m_m amount of milk or concentrate in kg
DM_m dry matter of milk or concentrate in %	DM_p dry matter of powder in %

¹ Instant, immediately available without any preparation; instantizing, manufacturing powdered extracts which are quickly soluble without any agitation.

The calculated data must be compared with the actual results.

- The difference between the theoretical and the actual data in % is the technological loss; efficiency η is the difference from 100%. In milk powder production the efficiency is 94–96%.

For product quality and cost control reasons there are other parameters of interest, e.g., sorption patterns of the dried components. Absorption (penetration of one compound into the volume of another one) or adsorption (adhesion of gaseous or liquid particles onto the surface of another material) of, e.g., steam (as moisture) by a dried product at a defined temperature is described by the sorption isotherms and expressed as relative humidity Φ . The correlation between relative humidity and water activity a_w (which is essential for the growth of microorganisms and for the shelf life of a product) is described in Section 2.3.1.1.

9.5.2.4. Filling

Filling of the cooled product is done either directly from the last cyclone of the cooling tower (or instantizer) or after intermediate storage from silos (or containers). For wholesale purposes milk powder is filled into paper bags that are coated on the inside with wax or into an inner bag made from plastic or plastic coated. Further, containers can be used for large-scale consumers or for intra-/interfactory transport; sometimes even tankers are used for this purpose.

Retail packs are boxes and cans with a plastic insert. Sometimes they are wrapped in cellophane. The net weights are normally 250 and 500 g. Portion-pack sizes are used for products such as coffee whiteners. The headspace in both the wholesale and retail packs contains an inert gas (N_2 , CO_2) in order to displace the oxygen.

9.6. Labeling, storage and transport

For labeling, which is a legal obligation, the statements made in Section 5.1.4. are valid here too. Additives must be indicated.

Long shelf life products must be stored and transported in such a way, they are not influenced by negative environmental factors. At 15 °C and a relative humidity of 75 %, skim milk powder has a minimum shelf life of 2 years, an average shelf life of 3 years, and a maximum shelf life of 4 years. For whole milk powder (in inert gas pack) the shelf life values are 1 year, 1.5 years and 3 years.

If the storage conditions for milk powder cannot be maintained (especially temperature) and the time has been exceeded, then the following product changes are observed:

- a) Increase of the moisture content and a slight reduction of the pH value
- b) Increase of the nonprotein nitrogen content (for a 1 year storage up to 60%) and a reduction of the heat stability of the proteins
- c) Vitamin losses: vitamin A up to 30%, vitamin C up to 70 % (4 week storage at 45 °C).

On the platforms of the transport vehicles, which need to be covered, no personnel or products other than dried milk products should be transported.

¹ Sorption is the absorption of gases, vapor or dissolved compounds into another material.

9.7. Quality evaluation

Products are evaluated organoleptically, chemical-physically and microbiologically. In the organoleptic evaluation, long-shelf life products should have a quality (taste and smell) close to that of the original product. For evaporated milk a slight cooked taste and smell should be noticeable; for sweetened condensed milk there should also be a sweet taste. Further, when dissolving milk powders, there should be a noticeable slight cooked taste and flavor.

For evaporated and sweetened condensed milk, the evaluation covers the aspects of flavor, taste, color, flocculation, whitening power (in coffee), heat stability, preparation and creaming, skin formation, viscosity, fat content, dry matter and sterility.

For sweetened condensed milk the evaluation covers the aspects of appearance, flavor, taste, consistency, protein content in the nonfat dry matter, fat content, milk dry matter content, SH value or pH value (based on milk), total dry matter, and moisture content; microbiological aspects are coliform bacteria, yeast and mold, coagulase-positive staphylococci and total plate count. For sterilized and UHT coffee cream, the same criteria are applied as for evaporated milk.

For the evaluation of milk powder and milk powder products, suspension are made with water for quality evaluation. The evaluation covers appearance, flavor, taste, cleanliness (dirt), fat content, pH value, sediment, moisture content, solubility and miscibility (only for instant powders), phosphatide content (only for buttermilk powder), lactic acid (only in powders from acidified milk) and microbiological criteria such as total plate count, sporeformers, coagulase-positive staphylococci.

In case there is an excess of milk and milk products in the European market, the European Union can remove production quantities from the market and store them in the form of skim milk powder (and butter) in order to regulate and stabilize the market conditions. So-called intervention skim milk powder has to meet the following quality standards:

Milkfat content	maximum 10.0 %
Moisture content	maximum 3.5 %
Titration acidity	maximum 19.5 ml 0.1 N NaOH
Lactate content	maximum 150 mg/100 g
Additives	None
Phosphatase test	Negative
Nondissolved particles	maximum 0.5 ml
Burnt particles	maximum 15.0 mg (sample disk B)
Total aerobic plate count	maximum 40,000 per g
Coliform bacteria	negative in 0.1 g
Buttermilk test	negative
Whey test	negative
Taste and flavor	clean, nonobjectionable
Appearance	white or slightly yellow, no dirt or colored particles

10 Whey and Whey Utilization

10.1. Terms and composition of whey

10.2. Importance and utilization of whey

10.3. Whey fermentation



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10 Whey and Whey Utilization

10.1. Terms and composition of whey

- Whey is the milk serum that is produced during the manufacture of cheese after separation of casein and fat during milk coagulation; sometimes lactase is used for coagulation.

Subject to the way in which casein is coagulated, i.e., by enzymatic rennet coagulation or by acid coagulation, we distinguish between sweet whey (rennet whey) and acid whey (quark whey). This also results in a different composition of the whey. In pure acid coagulation, calcium is removed from the calcium-casein complex, and calcium lactate is formed jointly with milk. Casein precipitates when the calcium is removed.

- Acid whey (quark whey) is a milk serum obtained during an acidic process and contains calcium lactate.

Enzymatic coagulation involves splitting of milk protein and the formation of calcium paracaseinate, i.e., calcium remains basically bound in the coagulated protein. Noncasein fractions such as β -lactoglobulin, α -lactalbumin, immunoglobulin and serum albumin are not precipitated and remain solubilized in the form of whey or serum proteins.

- Sweet whey (rennet whey) is a milk serum obtained during enzymatic coagulation of casein and is basically free from calcium; therefore no calcium lactate can be formed with lactic acid. Sweet whey cannot be converted into acid whey even with postacidification.

Another type of whey is industrial-grade whey, which is obtained, when protein coagulation is done with acids other than lactic acid, e.g., hydrochloric acid, sulfuric acid or acetic acid.

Table 10./1 Composition of fresh whey

		Sweet whey	Acid whey
Water	%	93–94	94–95
Dry matter	%	6–6.5	5–6
Lactose	%	4.5–5	3.8–4.3
Lactic acid	%	traces	up to 0.8
Total protein	%	0.8–1.0	0.8–1.0
Whey protein	%	0.6–0.65	0.6–0.65
Citric acid	%	0.1	0.1
Minerals	%	0.5–0.7	0.5–0.7
pH		6.4–6.2	5.0–4.6
SH value		about 4	20–25

The composition of fresh whey is shown in Table 10./1. The fat content depends in many cases from the cheese milk. A high fat content in the cheese milk leads to a high fat content in whey, especially when the cheese milk has not been homogenized. At a fat content of $> 0.1\%$ this whey must be decreamed. Cream is either processed into whey

butter or used in the fat standardization of cheese milk. Whey contains the vitamins B and C, vitamin B₂, lactoflavin, causes the green yellow color of whey.

10.2. Importance and utilization of whey

Whey has long been considered a waste product. It has been used in the manufacture of lactose, but mainly for cattle feeding. Smaller amounts went into drainage systems. However, whey must be seen as a by-product with valuable nutrients, whose manufacture or proper utilization has very high economic importance. Use of whey has the following advantages:

- a) Complete and efficient utilization of the raw material milk
- b) Manufacture of high-quality milk components for wide application in the food and pharmaceutical industry as well as for cattle feeding
- c) Reduction of wastewater load (BOD for whey is 30–60,000 mg O₂ per liter wastewater, see also Section 12.2.1).

Global whey production is estimated at 118 million tons, of which 66% is manufactured in Europe, 25% in North America, and 9% elsewhere. This shows the potential for the raw materials if it can be used properly.

Applications for whey are increasing constantly, in part because of improved separation techniques (ultracentrifugation, ultrafiltration, sterile filtration, reverse osmosis, electrophoresis, chromatography and others) and enzymatic hydrolysis.

Riedel¹ mentions the following areas of applications: foods, cosmetics, dietetics, sports food, baby food, cleaning agents. Whey products such as concentrated whey, whey powder, lactose-reduced and demineralized whey powder, whey protein concentrates and lactose can be used in amounts of 3–8% in soups and meat products (sausages). Modified whey products such as products with 90–98% lactose and whey protein isolates with a minimum protein content of 90% are also used in food production.

Other products are being evaluated in terms of their function and nutritional effects, e.g., lactoperoxidase, lactoferrin, immunoglobulin and proteose-peptone-fraction (evaluated as bacteriostat and an additive to baby food), enzymatic and/or high-pressure hydrolyzed whey proteins and fat-free whey proteins (tested as functional food ingredients), low-phosphate whey protein powder (tested persons with impaired kidney function), micro-milled whey protein powder [tested as a fat replacer (see 5.2.2)], lactose biopolymers, enzymes, vitamins, biomass, alcohol, biogas, organic acids, lactulose and lactitol, whey proteins (tested as replacers for melting salts), and whey minerals (evaluated as a salt substitute and for reduction of caries). Traditional applications such as whey for whey beverages, lactose, whey cheese and feed still remain.

In this chapter we will not deal with the multitude of whey applications in specific products, as the processes are extensive and vary widely. However, key aspects will be described, such as:

- a) Utilization of the nonprocessed whey
- b) Manufacture of whey concentrate and powder
- c) Manufacture of individual ingredients
- d) Fermentation of whey

Overview 10./1 shows the major utilization and application possibilities.

¹ Riedel, C.-L.: Molke-Rohstoffe für neue Produkte. Deutsche Milchwirtschaft, 4, 5 and 6, 45. Jg., 1994.

10.2.1. Utilization of unmodified whey

Cattle feeding. A major part of fresh nonprocessed whey is still used in cattle feeding and hog-feeding. The conversion efficiency in hog feeding, however, is only 20–40% based on the components found in whey. Scientists and cattle feeders are constantly looking for ways to better utilize the nutrients in whey, which is achieved by the manufacture of individual components and by fermentation. Further, it becomes more and more difficult and costly to supply farms with fresh whey, the farms are farther apart, and whey manufacturing is done in a few locations.

Whey beverage, drinking whey. The nutritious value of whey has been known for a long time, and whey has been considered as a health drink for centuries, especially in rural areas. Doctors have prescribed whey cures. However, the fairly bland taste and the short shelf life of fresh nonprocessed whey have limited its acceptance and distribution. New applications have opened up with the manufacture of whey and whey-containing beverages. The addition of fruit flavors and vegetable protein and reduction of the lactose content offers possibilities for new products. These products have achieved a market penetration and acceptance in those countries where they have been manufactured with the UHT and aseptic process.

An interesting application is lactose reduction by enzymatic splitting of lactose using lactase. This results in improved utilization by humans, and products can be developed for lactose-allergic consumers. Modern processes with enzyme immobilization on carriers permit economic enzyme utilization for lactose hydrolysis in whey permeate. Splitting lactose into glucose and galactose also has a sweetening effect (glucose has higher sweetening power) with a potential to reduce or eliminate the saccharose addition to whey beverages.

10.2.2. Utilization of whey concentrate and whey powder

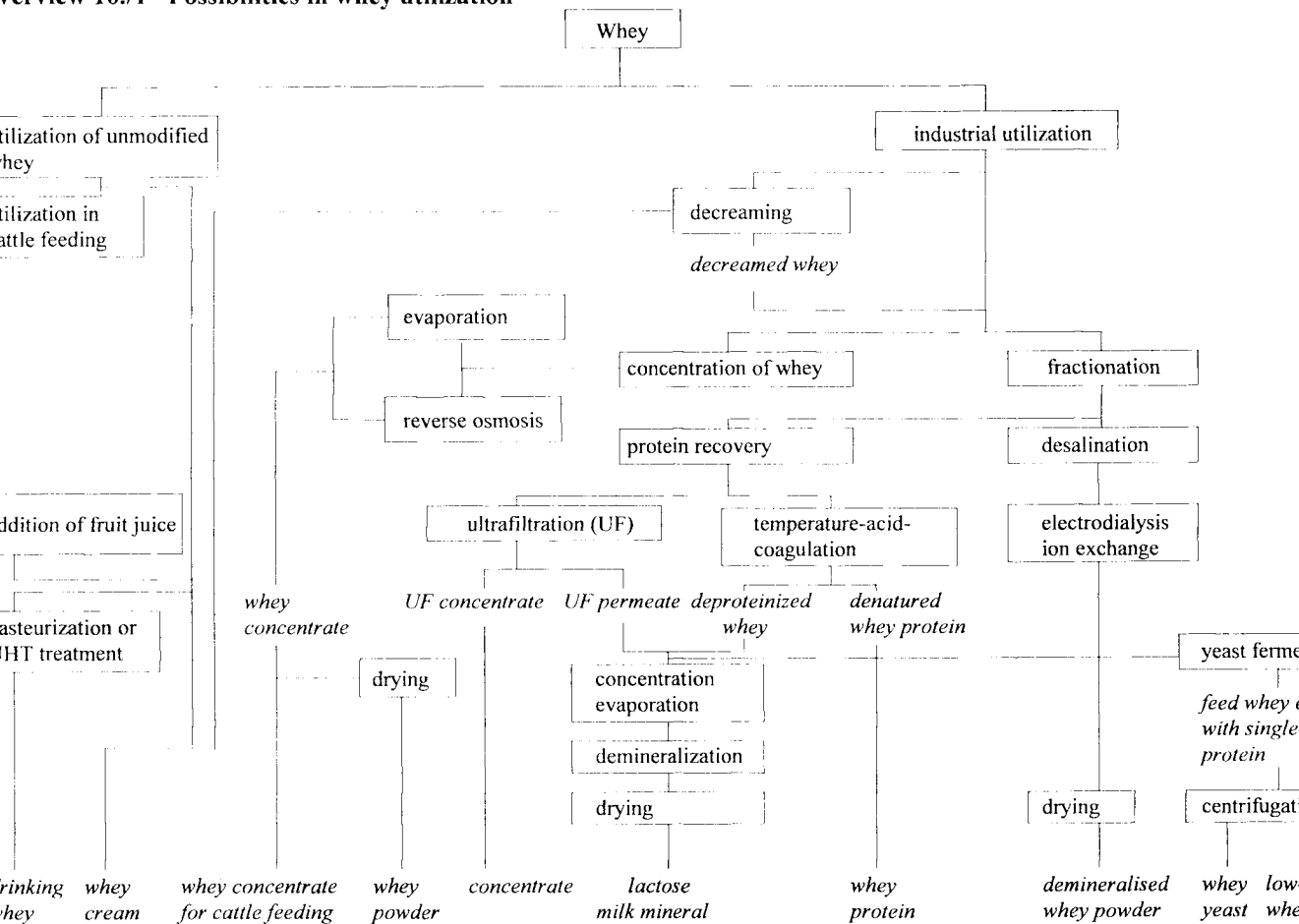
The base raw material for whey concentrate and whey powder is sweet whey or acid whey or a blend of both, sometimes also called industrial whey. The quality of this base material has a significant influence on the yield and quality of its components. It is always advantageous for the quality of whey concentrate and whey powder to process sweet whey and acid whey separately. During processing two basic problems become evident:

- a) High water content in whey (> 93%). Reducing the water content requires a high investment in equipment and machines with corresponding high costs.
 - b) Very short shelf life, due to the high plate count, rapid decomposition of the components and a pH reduction.
- The earlier whey is processed, the higher the yield and quality of the finished product.

Otherwise, pretreatment of the whey is advantageous or even necessary.

Pretreatment. Subject to the type of utilization and composition of the whey, pretreatment covers the aspects of processes stabilization (for quality reasons), decreaming and recovery of casein particles.

overview 10/1 Possibilities in whey utilization



Quality stabilization. Whey can be protected against rapid spoilage by:

- a) Immediate chilling to < 4 °C, permitting storage up to 24 hours without significant quality deterioration
- b) Heat treatment at 71–74 °C for a minimum of 15 s
- c) Addition of preservatives after decreaming, e.g., 0.05% hydrogen peroxide or 0.5% sodium or magnesium sulfite

Heat treatment causes further protein denaturation, which results in a quality degradation of the protein concentrate. In many cases options a) and c) may be considered, unless there are legislative limitations for preservatives.

Decreaming. If decreaming is required, it takes place immediately after manufacturing the whey, when it is not yet chilled. For this operation, self-cleaning or non-self-cleaning separators are used (see 4.2.3.4) which are specifically designed for whey decreaming.

For example, the self-cleaning separator type MRPX is conceived as a combination of a separator and clarifier. The disk stack is partitioned into two sections; the upper section is designed as a standard separator, the lower section has smaller disks. The sections are kept separate by a separation disk which nearly goes to the bowl periphery. Whey is pumped into the bowl at the periphery of the lower section. Here protein is separated in the form of solids, before the whey reaches the upper part for fat separation in the area between the disks and the upper bowl section. Accumulated solids are removed periodically from the lower part of the bowl, while cream is discharged from the upper part of the bowl as done in other decreaming separators.

Recovery of casein solids. During the manufacture of cheese, small casein agglomerates pass through a sieve installed at the outlet of the cheese vessel; the amount depends on the the curd structure and curd treatment. These casein particles, also called “dust,” are very similar to curd in their composition (dry matter, SH value) and could be used during cheese making. Hydrocyclones are commonly used for the recovery and refeeding of casein particles into the cheese vessel (Figure 10./1). Whey flows tangentially into the upper cylindrical part of the hydrocyclone. The centrifugal force, due to the rotation of the liquid, causes the particles to move toward the cyclone wall (with its bottom conical part); particles are decelerated and gently deposited on the bottom, being “carried” by the liquid. From there a whey/solid blend is discharged, containing about 10% of the total input of whey. The particle-free whey rises as a liquid column in the center of the cyclone and is then discharged. Several cyclones can be installed in series to improve efficiency.

Another technology for separating casein particles is sieve separation, for which vibrating shaking sieves are used (Figure 10./2). Fresh whey is first collected in a tank (with continuous stirring to avoid settling of the casein agglomerates) and then transferred (without any additional pressure) to the sieves. Due to the vibration and shaking of the sieve, the casein is separated and recovered in a nearly dry state. It is used not in the cheese making process but for other purposes (e.g., processed cheese manufacture). These machines are designed for capacities of 10–15,000 l of whey per hour. A process line for whey pretreatment is shown in Figure 10./3.

As membrane filtration is much more expensive than vacuum evaporation, this technology is used only in the fractionation of whey.

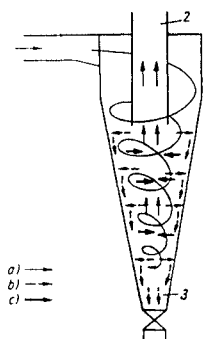


Figure 10/1 Principle of a hydrocyclone

- a) Whey with casein particles b) Solid/liquid blend
c) Whey containing no casein particles
(1) Whey inlet (2) Outlet for particle-free whey
(3) Outlet for solid/liquid blend

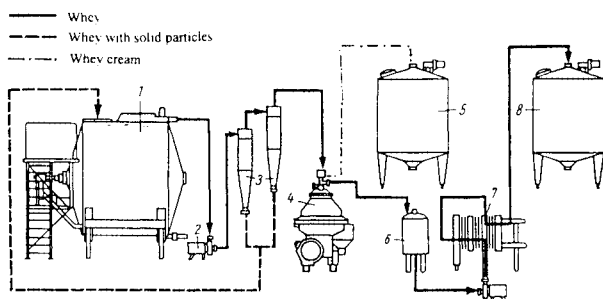


Figure 10/3 Process line for pretreatment of whey

- (1) Cheese preparation (2) Centrifugal pump (3) Hydrocyclones (4) Whey separator (5) Cream tank (6) Feed tank and/or for addition of preservatives (7) Plate heat exchanger for pasteurization or cooling of whey (8) Storage tanks for pretreated whey

Concentrate manufacture. Concentration of whey has the following objectives:

- Volume reduction for transport to other processing facilities
- Concentrate manufacture for drying into whey powder
- Manufacture of concentrated whey, sweetened or unsweetened

Concentration is most often done to a dry matter level of 40–60%; in special cases it is raised to 70%, and for condensed whey to a dry matter level of 25–28%. At high concentrations, there exists a supersaturated lactose solution. This can have negative effects on powder quality during drying resulting in a very hygroscopic product. Therefore fresh whey concentrate passes through a precrystallization process (6–8 h at 30 °C) with constant stirring. Eventually some milled α -lactose monohydrate is added for initiating crystallization (see Section 9.4.2.2).

Concentrate is usually manufactured in multi-stage falling film evaporators (see 9.5.2.2) or by membrane filtration (see Section 4.2.5.2). The advantage of membrane filtration is that the components are not subjected to thermal stress and are not further denatured. As this not a primary criterion in the manufacture of a standard whey powder and membrane filtration is more expensive than vacuum evaporation, this process is used only in the fractionation of whey.

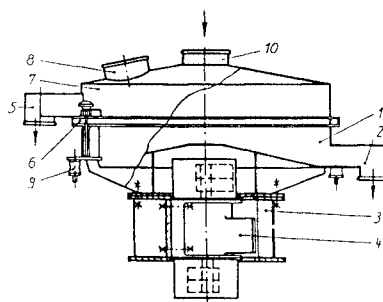


Figure 10/2 Vibrating shaking sieve, type VTS

- (1) Base cylinder (2) Fine particle outlet (3) Motor frame (4) Vibration motor (5) Coarse product outlet (6) Sieve frame (7) Cover with tangential outlet duct (8) Inspection hole with rubber cover (9) Springs for vibration control (10) Inlet for product

Drying. The standard types of whey are labeled according to their raw material base, i.e., sweet whey or acid whey. They can be manufactured in the form of sugar-reduced, demineralized or protein-enriched products, and all of them can be made with the addition of lactose. The following types exist:

- a) Sweet whey powder—manufactured from sweet whey by removing the water with a maximum moisture content of 5% and minimum of 70% lactose
- b) Acid whey powder—made from acid whey or postacidified whey, having a maximum moisture of 6% and minimum of 60% lactose
- c) Demineralized whey powder—made from demineralized sweet or acid whey, with a maximum mineral content of 2.5% and a maximum moisture content of 6%
- d) Protein-enriched whey powder—made from sweet or acid whey, enriched with protein, having a minimum protein content of 22% and maximum of 8% moisture content.

Whey powder is basically manufactured in the same way as milk powder. Powder for cattle feed is often manufactured on a roller-drier. High-quality products are spray dried, and for special applications they are instantized.

10.2.3. Manufacture of individual ingredients (fractions)

The fractionation of whey mainly involves protein manufacture, lactose manufacture and demineralization. The manufacture of lactose and of demineralized products must be preceded by protein removal, and this is called a step fractionation.

10.2.3.1. Protein extraction

Whey contains on average 0.8% protein in the form of serum protein, which corresponds to about 20% of the total milk protein. In addition, there are casein agglomerates as fine particles, whose separation has been described in Section 10.2.2, as well as other casein-based products.

Numerous applications for whey proteins have been mentioned in Section 10.2, and new fields of applications are explored, mainly requiring new, modified and more gentle production methods. The key objective is to utilize the highly nutritious protein for human consumption.

- Whey protein is protein that has been separated from whey by chemical and/or physical methods. It has two main fractions, β -lactoglobulin and α -lactalbumin.

Whey protein can be separated by membrane separation, precipitation and centrifugation.

Membrane separation. For this type of separation, ultrafiltration (UF) is used primarily; its principles have been described in detail in Section 4.2.5.2.2. The key advantage of this process is that the protein remains in its original state, and there are no thermal or acid effects. The process is designed in accordance with the quality of the products.

The concentrate is then mostly spray dried. For powders manufactured in such a way, the basic parameter for quality evaluation is the raw protein content. The composition of some products is shown in Table 10./2.

Processing parameters for the ultrafiltration of rennet whey when using cellulose acetate membranes are as follows:

UF pressure	3–7 bar
UF temperature	
for batch operation	10 °C ± 5 °K
for continuous operation	50 °C ± 5 °K
Flow velocity	> 1.5 m/s
Flowrate (flux)	20–60 l/m h
Dry matter of concentrate	up to 22%
Pretreatment of whey	pasteurization and deaerating (fat content < 0.05 %)

Cleaning and disinfection of the membranes

Stage 1	0.5% phosphoric acid solution with surfactant at 30–40 °C for 30–45 min
Stage 2	0.3% phosphoric acid solution and 0.05% peracetic acid solution at 10–15 °C for 30–40 min.

This process profile permits selective separation for:

α -Lactalbumin	70%
β -Lactoglobulin	95%
Blood serum albumin, immunoglobulin and fat	100%
Lactose	2–8%

Table 10./2 Composition of some whey products manufactured by ultrafiltration and spray drying¹

	Raw protein in %			Permeate in %
	35	65	80	
Water	4.6	4.2	4.0	4.0
Raw protein	36.4	63.0	81.0	4.7
Net protein	27.7	59.4	75.0	1.5
Lactose monohydrate	46.5	21.1	3.5	80.0
Fat	2.1	5.6	7.2	0.0
Minerals	7.8	3.9	3.1	7.9
Lactic acid	2.8	2.2	1.2	3.1

¹ Muir, D.D., Banks, J.M.: Developments in membrane technology. *Journal of the Society of Dairy Technology* **38** (4), 1985.

Protein extraction by precipitation. Here protein is precipitated before the separation of whey, which results in stronger denaturation. Precipitation can be done in different ways, e.g., by adding neutral salts, iron or copper hydroxide, colorants (thiazine brown) or gallic acid extracts (tannin). In most cases a heat precipitation is performed, in which whey, at a pH of 4.4–4.8 (SH 12–16) is heated to 90–95 °C and kept at this temperature for 30–50 minutes. The pH range must be maintained if possible. If the pH is too low, acids can be neutralized by adding alkali. As a rule, for a reduction of SH 10 in 1000 l it is necessary to add:

Baking soda, calcified	1.3 kg	Baking soda, crystallized	3.6 kg
Calcium hydrate	0.9 kg		

Alkali is added during the preheating in small amounts in order to avoid foaming of the solution. If pH is too high, hydrochloric acid, citric acid or lactic acid can be added.

For the purpose of precipitation, whey is filled into stainless steel or enameled tanks, that have a tubular heating system for steam heating or are directly heated with steam (steam injection). After the reaction, protein sinks to the floor as a sediment. After decanting the whey the protein is filled into filter bags and drained until the desired dry matter content has been reached.

This protein extraction technology results in a yield of 20–25 kg whey protein per 1000 l of whey, with the following composition and characteristics:

Dry matter content	≥ 20%
Moisture content	≥ 80%
Appearance, color	white-gray to slightly yellow
Flavor	clean, slightly acidic
Taste	clean, neutral to slightly acidic
Structure	paste to grainy

This protein can be dried in drying chambers or on belt drier, after which it is milled and filled like milk powder.

Centrifugation. The Centri-whey process (Figure 10./4) has been developed so that heat-denatured whey protein can be fed back in certain cases into the cheese process (in certain cases).

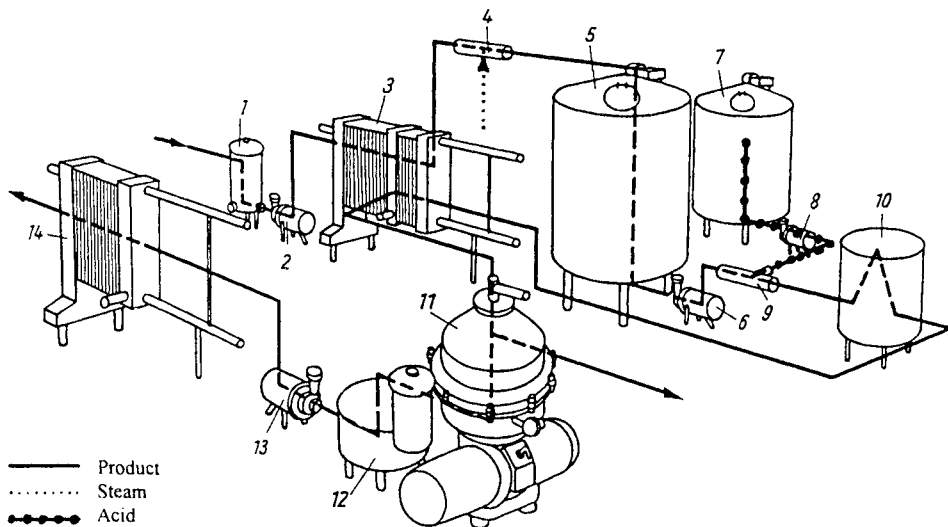


Figure 10./4 Process line for the manufacture of whey protein for the cheese line system “Centri-whey”

(1) Buffer tank with floating device (2) Centrifugal pump (3) Plate heat exchanger (4) Steam injection (5) Storage tank (6) Centrifugal pump (7) Acid tank (8) Acid pump (9) Acid injection (10) Tubular holding section (11) Self-cleaning separator (12) Collecting vessel (13) Protein concentrate pump (14) Plate heat exchanger

In this process fresh whey is separated at 30 °C for removal of fat and casein, chilled to 8 °C in order to stop the autoacidification and then transferred into a tank. During storage, the optimal pH of 6.2–6.3 can be set by adding alkali. Processing continues by passing the whey from the balance tank (1) via a pump (2) to a plate heat exchanger (3); whey is heated to 70 °C and the temperature is raised further by direct steam injection to 90–95 °C (precipitation temperature). Thereafter the hot whey remains in a holding tank (5) for 10–15 min, where sedimentation of flocculated whey protein is avoided by constant stirring. A pump (6) discharges the whey and it reaches an acid injection tube. From an acid tank (7), the required amount of salt or acid is injected with a pump (8), so that the optimal precipitation pH of 4.6–5.0 is obtained immediately. The heat-denatured proteins are completely precipitate in the tubular holding section during a residence time of 30 s, and whey is cooled to 40 °C in a plate heat exchanger (4) and transferred to the self-cleaning separator (clarifier) for separation into protein concentrate and clarified whey. After 2–3 min, 10 kg of protein concentrate with a dry matter content of 15% can be removed from the separator and are transferred into a vessel (12). The concentrate is then transferred back directly via a pump (13) or is chilled in a plate heat exchanger (14) until it is further processed. The protein-free clarified whey is an excellent raw material for the production of lactose and for demineralization.

Concentrate obtained in this way has the following composition:

Dry matter	14.70%
Protein	9.10%
Lactose	5.45%
Minerals/Ash	2.15%
SH number	31.6

10.2.3.2. Milk sugar (lactose) manufacture

Importance and definitions. Compared to saccharose, lactose has the following varying properties:

Solubility in 100 g water

Saccharose	at 25 °C	110.0 g
Lactose	at 25 °C	22.0 g
	at 50 °C	43.7 g
	at 90 °C	143.9 g

Sweetening power	Saccharose	100
	Lactose	25

Low hygroscopicity: in 25 days of storage at 25 °C and 100 % rel. humidity, only 1.38% of moisture are absorbed

Energy content 17 kJ./ g

Lactose has special properties, which make it ideal as a carrier substance for pharmaceutical and dietetic products, e.g., artificial sweetener or pharmacological ingredients, pressed into tablets at a later stage.

Another property of lactose is that it is a suitable nutrient for many microorganisms; e.g., it is used in the production of penicillin and other antibiotics. Depending on the type and sophistication of the process, we can distinguish between raw lactose and pure lactose.

- Raw lactose is manufactured from whey after depeptization, evaporation and crystallization or any other similar process and is dried.
- Lactose is manufactured from raw lactose by raffinination and contains more than 97% of lactose monohydrate. Lactose with pharmacological properties has to comply with pharmacological standards.

The manufacturing process can be separated into two key parts (raw lactose extraction and lactose production) as a function of the type. The first part is done in a dairy; raffinination is most often done in centrally located specialized lactose plants.

Production of raw lactose. The base material is depeptized whey with a minimal protein content, which has been adjusted to a pH of 6.0–6.5 (SH 7–10) before concentration by adding calcified bicarbonate. The addition of a solution of lime to nearly neutral pH helps in removing minerals, especially phosphates.

Concentration. The whey is concentrated in evaporators (see Section 9.2.2.2) to a concentration degree of 1:15. Concentration is assumed to be finished, when the specific density has reached 30–33 °Bé, corresponding to a dry matter content of 55–60%. Table 10./3 shows the close relationship between the degrees Baumé and the dry matter content.

Table 10./3 Baumé and % dry matter (source Kuntscher)

Bé %	Dry matter
3.7–4	5.5–6.5 (fresh whey)
14	20–25
20	34–38
26	44–48
30.5	52–54
33	55–60
35	62–65

Crystallization. Crystallization of lactose is achieved not with the highest sugar concentration and rapid cooling, but by slow cooling to initially 30 °C. After a storage period of 3 hours, it is cooled further to 20 °C, and after another 4 hours it is cooled to 10–12 °C; every 2 h, the concentrate is stirred carefully, so that after 24 h a slush with coarse crystals has developed. Crystallization is accelerated by adding well-developed crystals to the concentrate, which can have smaller subcrystals on the sides and edges. The relationship between crystallization, time and temperature are given in Table 10./4. For crystallization a concentrated sugar solution is pumped from the evaporator to a storage tank, where it is cooled gently, while stirring slowly with a wire mesh stirrer.

Centrifugation. Crystallized milk sugar (lactose) is then separated from the solvent in continuous horizontal separators (decanter) or, for lower capacities, with periodically discharging perforated centrifuges that have inserts of filter cloth. Depending on the type of separation and the separation efficiency, a final moisture content of 8–20% is achieved.

Table 10./4 Relationships for lactose crystallization (Rahn-Sharp)

Time in h	From 60% crystallized lactose in % of insoluble lactose at the following temperatures in °C				
	0	10	20	30	40
0	40	40	40	40	40
1	42	45	54	70	89
2	43	50	64	85	98
5	48	62	83	98	99.9
10	55	76	95	99.9	100
100	97	100	100	100	100
200	99.8	100	100	100	100

Drying. The moist raw lactose must be dried, unless it is refined immediately, otherwise mold would grow after a few days. For small quantities drying cabinets are used, where the product is spread onto trays in thin layers and is dried at 70–80 °C. For larger capacities and for continuous operations, either a belt or a fluid bed drier is used, operating at 90–93 °C with a drying time of 15–20 min. Dried raw lactose, also called technical lactose, is then packed like milk powder.

Extraction of residues of raw lactose. The separated molasses still contain 30–35% lactose, some residues of protein and a large percentage of minerals. It must be resubmitted to an extraction process in order to improve the lactose yield. The residual molasses is then utilized as cattle feed.

Protein is removed from molasses by heat, adjusted to a pH of 4.6–4.8, concentrated to about 36 °Bé and crystallized, with a crystallization time of 60 h. Separation is done in centrifuges. Molasses is used in demineralization or as cattle feed.

Production of pure lactose by raffination. Raffination removes all nonsugar components (colorants, protein, dissolved and crystalline minerals) or reduces them to a minimal level. For this purpose, raw lactose is dissolved with warm water (about 50 °C) in a vessel, (which has temperature control devices and a stirrer); the density is set to 1.116 g/ml = 15 °Bé.

About 2% charred bones or activated carbon (based on the amount of sugar) is added to this solution to bind all nonsugar components in an adsorptive manner. This solution is heated to 105 °C by direct steam injection and then passes through a heated filter press in order to separate the adsorbing material and all bound foreign matter. The clear filtrate is concentrated in evaporators to about 35 °Bé; the concentrate is then processed as done in the manufacture of raw lactose. Drying is done mostly in vacuum cabinets at 55–60 °C. The discharged raw molasses can be concentrated together with raw whey; the small amount of distilled water used for postwashing is reused for dissolving the crystal slush.

In this type of process, about 3.5 kg of raw lactose or 3.0 kg of refined lactose can be obtained from 100 kg of decream whey with a dry matter content of 6.5%.

Process line for the manufacture of lactose (Figure 10./5). In this continuously operating process line, depeptized whey goes from a balance tank (1) into a multistage falling film evaporator, is concentrated to the targeted dry matter content and is then transferred into a tank (3) for crystallization. Thereafter, the lactose crystals are separated from molasses in two stages by a decanter (4), resulting in raw lactose of 90% dry matter content. Raw

lactose is then transferred to the drying section (5), where continuous hot-air drying is done, or is brought directly to the raffination process.

In the raffination section of the process line, raw lactose is redissolved with water in a tank (6), adsorbing reagents are added, and the solution is heated in a plate heat exchanger. The hot solution passes through alternatively charged filters (8) into a plate cooler (9), where the crystallization temperature is set, and then into the crystallization tank (3). Thereafter crystallized lactose is separated from the molasses in a decanter (4) and is transferred to the drying station (5). Dried lactose is finally milled and packed.

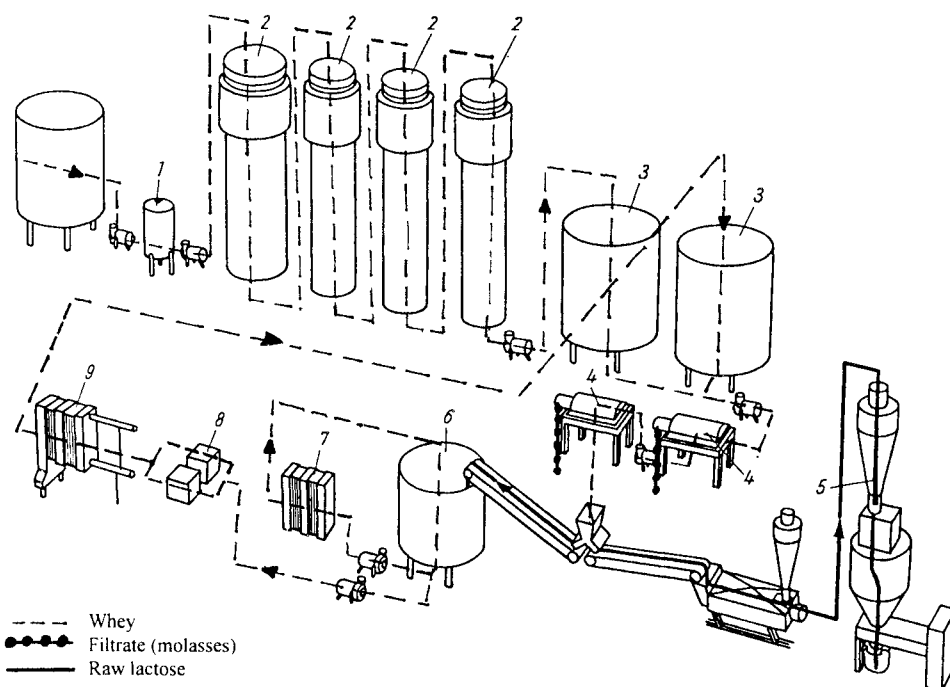


Figure 10.5 Process line for the manufacture and raffination of lactose

(1) Buffer tank with floating device (2) Falling film evaporator (3) Crystallization tank (4) Decanter (5) Drying installation (6) Dissolving tank (7) Plate heat exchanger (8) Filter (9) Plate heat exchanger

10.2.3.3. Desalination

For the manufacture of demineralized or mineral-reduced whey products, membrane separation processes are used to remove salts. As nearly all salts in milk can be ionized and thus move in an electric field, a demineralization can also be done by electro dialysis¹ or ion exchange or can even be done directly in milk. Areas of application are:

- Stabilization of milk against heat coagulation by partial replacement of Ca^{++} by Na^+ ions, sometimes with a simultaneous increase of the pH value of the milk
- Manufacture of dietetic milk products such as low-sodium milk by replacement of Na^+ ions by K^+ , Ca^{++} and Mg^{++} ions

- c) Demineralization and deacidification of whey during the manufacture of lactose and baby food products by replacing the cations by H^+ ions and the anions by OH^- ions with corresponding pH control
- d) Manufacture of lactic acid from whey
- e) Removal of radioactive products from milk, such as ^{90}Sr , ^{85}Sr , ^{137}Cs and ^{131}I

10.3. Whey fermentation

Lactose in whey can also be used in yeast fermentation. In this process, lactose serves as a nutrient for the used microorganisms. Apart from the production of metabolic products, all nutrients are extracted from whey, which permits easy discharge without any ecological disadvantage.

The metabolic activity of the participating microorganisms results in production of CO_2 , ethanol and single-cell protein as biomass. The enriched whey can be used directly in cattle feeding, or the biomass can be separated and dried as a feed concentrate. A corresponding preparation of the single-cell protein can lead, within certain limitations, to application for human food. Further ethanol and CO_2 are used in various applications and ethanol is manufactured from whey on a large industrial scale in some countries. After fermentation of the lactose the BOD in the residual liquid (see 12.2.1) has been reduced to such a level that the liquid can be discharged directly into the municipal wastewater system without any further processing.

Process. Whey can be fermented directly or fractionated before fermentation; the following substrates are available:

- a) Raw whey
- b) Ultrafiltration permeate
- c) Molasses from lactose crystallization
- d) Residual whey before the centrifugal protein separation

The substrates must be adjusted for the microorganisms before fermentation, especially in regard to pH and temperature. Direct fermentation by yeast does not make much technological and economic sense, as apart from *Saccharomyces fragilis* only a few yeasts can use lactose as a substrate for fermentation. Further, the fermentation process cannot be optimized to achieve a theoretical yield of 0.5 g yeast cells per g of lactose. The required intensive aeration, for the growth of yeast, is difficult to achieve.

An efficient process involves the use of a combined culture of bacteria and yeast (e.g., lactobacilli and baker's yeast), permitting a two-stage fermentation. During the first phase, bacteria ferment lactose into lactic acid at a pH of 4.5–5.0. By adding inorganic acids such as sulfuric acid, the pH can be lowered to the optimal value, which is about 2 for yeast growth. In the second phase, yeast consumes this acid, thus raising the pH value again to 6.5. At the same time, yeast cells are autolyzed and provide more nutrients for the other yeast cells. The entire fermentation process goes over 10–60 h. A process line for the whey fermentation by yeast is shown in Figure 10./6.

¹ Dialysis: separation of low-molecular-weight particles of colloids with the aid of semipermeable membranes.

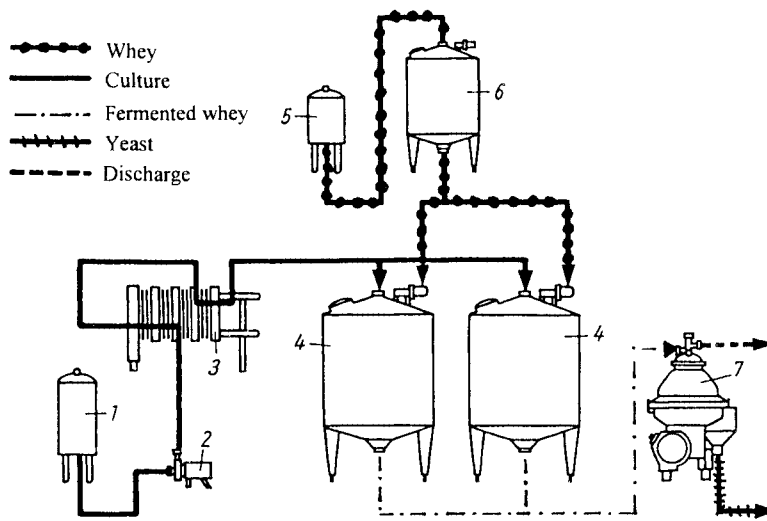


Figure 10./6 Process line for whey fermentation with yeast

(1) Buffer tank (2) Centrifugal pump (3) Plate heat exchanger (4) Fermentation tank (5) Tank for culture (6) Blending tank (7) Yeast separator



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11 Cleaning and Disinfection in a Dairy

11.1. Terms and definitions

11.2. Type and characteristics of dirt

11.3. Form, materials and surface characteristics of the surfaces to be cleaned

11.4. Requirements, type and effects of cleaning and disinfection agents

11.5. Cleaning and disinfection processes

11.6. Quality of utilized water



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11 Cleaning and Disinfection in a Dairy

11.1. Terms and definitions

The safety and quality of products depends to a large extent on proper cleaning and disinfection of machines, equipment, tools, installations, process lines and rooms. Time required for this corresponds to about one fourth of the total working time.

Per 1 ton of processed milk, about 1.7 kg of alkali and 0.6 kg of acid are required as chemical agents. In addition water is required as a solvent and rinsing agent and steam for energy supply and sterilization. A considerable effort is to be made to dispose of the used cleaning and disinfection agents in the form of ecologically acceptable waste. In order to use these agent economically and obtain an optimal design of the cleaning and disinfection process, the following aspects must be considered:

- a) type and composition of the dirt
- b) shape, material and surface characteristics of the areas to be cleaned
- c) requirements, type and effectiveness of the cleaning and disinfection agents
- d) cleaning and disinfection process
- e) quality of the used water

In order to establish a clear objective, the tasks for cleaning and disinfection must be known. In the dairy industry, as in the food industry in general, the following definitions can be used:

- Cleaning is the complete removal of all residues of milk, milk components and other dirt, whereby complete coverage of the cleaned areas with cold water must be achieved.
- Disinfection is the complete inactivation of all pathogenic microorganisms and the reduction of all non-pathogenic microorganisms to such a low level, they do not detract from the quality of the products.

Cleaning and disinfection are interdependent and the basic rule applies:

- First cleaning, then disinfection. Effective disinfection can be done only on well cleaned surfaces.

The two activities can be done simultaneously, if the concentrations of the solutions are correct, pH is suitably set and time and temperature are sufficient; i.e. cleaning can be combined with disinfection. This kind of process should be achieved, as it permits more efficient and economical design of the total cleaning and disinfection process.

11.2. Type and characteristics of dirt

The dirt encountered in dairies consists mainly of adhering products and product particles made of dairy components such as fat, protein and milk minerals. Lactose plays only a secondary role (from a dirt point of view), except during manufacture. The different concentrations of these components in the product residues and their different adhesion characteristics and buildup on surfaces must be considered. Anything from a soft deposit to burnt-on stone-like deposits may be encountered. The extent of and the prob-

lems in cleaning depend on factors such as whether there has been a heat or acid coagulation of the protein residues and the fat content of the dirt.

Nearly all kinds of dirt have very high level of harmful germs, e.g., coliform bacteria, spoilage agents, organisms for proteolysis, yeast, mold and lactic acid bacteria; pathogenic microorganisms cannot be excluded. Other types of dirt are organic and inorganic dirt particles such as sand and dust, which have found their way into the dairy in different ways.

11.3. Form, materials and surface characteristics of the surfaces to be cleaned

Shape. The different shapes of the objects, that must be cleaned, require special cleaning methods. Difficult-to-clean locations, e.g., corners, angles, joints, pipeline fittings, flexible hose fittings and closed/covered machines can be cleaned mechanically only with difficulty. The following disinfection can be successful only, if all dirt particles have been removed during the cleaning process.

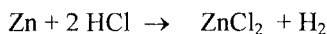
Material. In most cases, cleaning areas consist of steel, mainly stainless steel (CrNi steel); there are also glass surfaces, plastic, rubber and wood objects; and ceramics and earthenware. All materials, with the exception of steel, are relatively inert to cleaning agents, but glass and plastics can be destroyed by physical means, especially sudden and large temperature shocks.

Metals are not sensitive to temperature shocks but can be attacked more or less easily by chemical agents, which can lead to corrosion and ultimately destruction of the metal.

- Corrosion is a destructive attack on metals by chemical or electrochemical reactions that start at the surface.

A distinction is made between surface corrosion (which is relatively harmless, as its attack is spread over the entire surface) and localized corrosion (holes), where a hole- or groove-like damage can occur in spots. Localized corrosion can cause considerable material destruction.

Corrosion process. Basically corrosion happens in two ways. When metal is brought together with an acid, salt and of hydrogen are formed, e.g.,



The stronger the acid and the nobler the metal, the stronger is the salt formation.

- All metals, e.g., Cu, Al, Fe and Zn with the exception of stainless steel should not be cleaned with a strong acid or alkali.

The second path to corrosion arises when two different metals are jointly in contact with an electrolyte (acid, base, salt solution). In this case a galvanic element forms; its strength depends on how far apart the elements are in the periodic table of elements (electrochemical voltage). The farther apart, the higher the electrochemical voltage. Figure 11./1 shows such a localized element, which was formed when a tin-coated copper pipe was damaged and both elements were brought into contact with an acid.

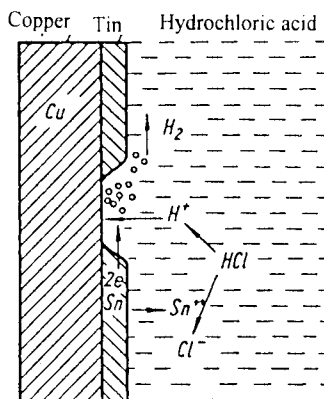


Figure 11/1 Localized element, created by the simultaneous contact of hydrochloric acid with two metals that are bonded together

The hydrogen ions (H^+) of an acid discharged on the nobler element Cu; this positive charge is neutralized on the less noble element Sn, and Sn^{++} ions of the metal Sn are solubilized.

- Compounds of parts of different metals or metal coatings of different kinds should not be cleaned chemically if simultaneous contact with an acid cannot be excluded.

Surface structure. The smoothness of the surface structure can be influenced by a mechanical or chemical treatment, and this influences the adhesion of dirt particles. Milk and milk components, microorganisms or dirt particles of different origins adhere much more strongly on rough surfaces or surfaces with large pores than on smooth surfaces.

Corroded surfaces, wood and cracked rubber or plastic tends to have a higher level of dirt. Metallic surfaces are coated with enamel or plastic in order to have a very smooth and easy-to-clean surface.

In an intensive CIP process with good flow conditions (turbulence) rough surfaces can be cleaned efficiently.

11.4. Requirements, type and effects of cleaning and disinfection agents

11.4.1. Requirements and type of agents

The following general requirements must be met by cleaning and disinfection agents:

- a) Assurance of the required cleaning and disinfection effect
- b) Compliance with physiological and toxicological requirements
- c) Approval and certification

As no agent can meet all cleaning and disinfection requirements, different reagents have been developed and used for different areas of application. Cleaning and disinfection agents can be classified into two groups according to their mode of action:

- a) Mechanical means
- b) Chemical means

In many cases a combination is attempted. The term “agent” is used here for parameters (e.g., pressure, time, temperature), tools (brushes and others) and reagents (chemical agents).

Mechanical-physical means. This group comprises mainly temperature (heat), reaction time, pressure, type of flow condition and intensity (velocity), and brushes, sponges, scrapers and cloth.

Working with brush and water is considered a cleaning method of the past. However, in many cases it is still the cheapest and sometimes the only way to achieve the desired cleaning efficiency. It must be ensured, that brushes and scrubbers are cleaned and disinfected themselves after use, and that they are stored in a dry place. Otherwise there will be very strong growth of microorganisms, which will later reduce the effects of cleaning (recontamination).

Chemical agents. The chemical agents are classified according to their effect, i.e., cleaning (C) or disinfection (D) or combined, and whether they are acidic, basic or chemically neutral. Their activity can be determined by titration, i.e., by the concentration c (H_2SO_4) of 50 ml per ml (0.5 N), or the acidity by the consumption of lye [e.g., at a concentration c (NaOH) of 25 mol per ml (0.25 N)]. The disinfection effect can be seen in the context of activated carbon or peracetic acid in mg/l. Sensors can measure, e.g., the electrical conductivity at 20 °C in mS/cm.

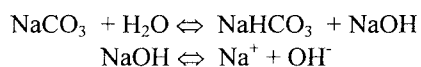
CP	alkaline reagents for general and manual cleaning in the dairy, cleaning of transport and storage installations as well as process lines
CB	cleaning agent for alkaline bottle cleaning
CAP	cleaning agent for acid cleaning of milk processing lines and transport and storage facilities
DP	disinfection agent for milk processing lines and transport and storage facilities
CDP	cleaning and disinfection agent for milk processing lines and transport and storage facilities

For a clear definition and because of the primary importance of the active components of combined cleaning and disinfection agents, the term “cleaning agent with disinfecting effect” is commonly used.

11.4.2. Effects of cleaning agents

The mechanical-physical means were described in Section 11.4.1. Their effect, together with that of chemical agents, is described at the end of this section. Chemical agents are mostly aqueous solutions that are acidic, basic or neutral.

Alkaline agents. Basic components are sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium carbonate (Na_2CO_3), sodium phosphate (Na_3PO_4), and sodium pyrophosphate ($\text{Na}_4\text{P}_2\text{O}_7$) in different combinations and concentrations. Their cleaning effect is based on the splitting off of hydroxyl ions in aqueous solutions (base).



Acidic agents. There are two groups of these types of cleaning agents. One group contains inorganic acids and salts (the most widely known is the nitric acid HNO_3 ; other agents are

phosphoric acid H_3PO_4 , amidosulfonic acid $SO_3(OH)-ONH_2$ and sodium hydrogen sulfate $NaHSO_4$, the other is the organic acid type (e.g., acetic acid $H_3C-COOH$; citric acid $CH_2-OOH-C(OH)-COOH-CH_2-COOH$; and formic acid $H-COOH$). Their activity is based on the splitting off of H^+ ions and means of dissolving calcium and magnesium residues in mineral deposits.

Inhibitors. These serve mainly as anticorrosive agents, by reacting with a metallic surface and forming a protective layer. The most common inhibitors are alkaline silicates (Na_2SiO_3) and alkaline phosphates (mono-, di-, tri- and hexametaphosphate), with hexametaphosphate binding the hardness of water and reducing hardness deposits.

In addition, small amounts of surfactants are added to alkaline cleaning agents, such as alkaline sulfates, alkaline sulfonate or fatty acid products, which reduce the surface and boundary layer tensions and thus permit cleaning agents to penetrate easily into dirt.

Neutral agents. Their aqueous solutions have a pH of 6–8, and in reactions they are slightly acidic or alkaline. They do not cause any corrosion and they are able to dissolve fat to a large extent. Because of their surface activity, they are very good surfactants.

The strong adhesion to the cleaned surface is a disadvantage, because in spite of intensive rinsing with water, contact with the product cannot be excluded. A commonly used agent is, e.g., “Fit,” which is based on a fat alcohol sulfonate. Other common agents are tensides such as quarternary ammonium compounds (quats) and amphotensides. They are classified according to the charge of the hydrophobic radical as anion active, cation active and amphotytic groups. Iodophores are included in this group.

Reaction of the cleaning agent. During cleaning different factors react with each other. The reactions of the physical factors pressure and temperature are explained in the section cleaning process. Dirt is removed mechanically by brushed, scrapers or sponges. When cleaning with solutions at low or high pressures, the cleaning efficiency is determined by hydrodynamic factors such as velocity, turbulence of the liquid, impact pressure and impact angle for the liquid jet.

The success of a cleaning and disinfection process also depends on surface tension (see 2.3.2.8). The lower the surface tension of a cleaning solution, the better the formation of a liquid film over the surface to be treated and the better the penetration into the pores of the dirt as well as into surface cracks (Figure 11./2).

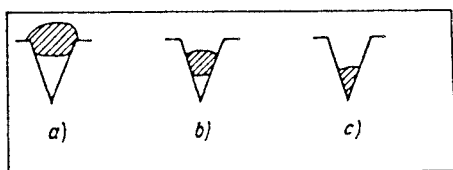


Figure 11./2 Penetration of different media into a microcrack as a function of the surface tension (Pescheck)

a) Water 7.2 N/mm² b) Milk 5.2 N/mm²
c) Cleaning solution 3.5 N/mm²

The effectiveness of the chemical agents depends on the type of dirt. Dirt-containing proteins must be hydrated first, forming positively and negatively charged ions (protein ions). The protein ions are then charged by the easily absorbed ions of the cleaning agent (hydrogen and hydroxyl ions) and are split off. The small particles that result are bound to

water, which surrounds them as a protective hydrate and makes them colloidal (peptization).

- Peptization is the reconversion of a gel into a colloidal solution, or a sol (reversion of coagulation).

Fats are emulsified by alkaline cleaning agents and turn into soap (small amounts), which makes them easily transportable; on the other hand, soluble components such as soap and glycerin are formed. Due to the low concentration of lye, the soap reaction is not very pronounced. Surfactants increase the emulsifying action.

Stonelike deposits of milk minerals and salts of the water are best dissolved by acidic reagents. Mostly calcium and magnesium compounds must be removed, for which nitric acid (inorganic acid) and acetic acid (organic acid) are best suited.

The peptization of proteins, emulsification and soaping of fat and removal of stonelike deposits are best supported by mechanical means. The cleaning can be separated into six phases:

- a) Contact phase—cleaning solution comes into contact with the surface.
- b) Coating phase—the surface active components coat the dirt; in this phase the temperature of the cleaning agent are decisive.
- c) Penetration phase—particles penetrate into the dirt layer, and larger agglomerates are formed.
- d) Dispersion phase—particles are finely distributed, some already solubilized in ion form.
- e) Emulsion phase—insoluble compounds are emulsified and kept floating; the extent of the removal depends on hydrodynamic influences (rinsing action).
- f) Post-cleaning phase—displaced compounds are carried away and should not sediment.

Cleaning speed, i.e., the amount of dirt removed from the surface per unit time, is important for the cleaning process and is influenced by:

- a) Temperature of the cleaning solution
- b) Type and concentration of the cleaning solution
- c) Type of dirt
- d) Applied mechanical energy (flow velocity, turbulence, impact pressure)

However, none of these factors can be increased arbitrarily in order to improve the cleaning effect. When the typical parameters for a given cleaning agent are exceeded, the cleaning effect can become worse.

11.4.3. Effects of disinfection agents

Like cleaning agents, disinfection agents (for inactivating microorganisms) can be classified into physical and chemical modes of action.

Physical means. Heat as a basic agent for the inactivation of microorganisms is applied to the disinfection areas in the form of hot water, steam or hot air.

The desired disinfection effect is achieved with hot water or steam if the surface, after it has been carefully cleaned, reaches a temperature of ≥ 85 °C for 1–5 min. Achieving

sterile areas requires 120–130 °C for 15–20 min, and if dry heat is used, then it requires 160 °C for 2 hours.

Microorganisms can be removed effectively from air, gases and liquids by filters. Short-wave beams are used for germ reduction on surfaces and in gases and liquids. With corresponding doses, especially for extremely short-wave beams such as x-rays or gamma rays, sterility can also be achieved; however, safety precautions must be taken and legal requirements met, so their application is restricted to a few special cases.

There is interest in UV light for the sterilization of air; the optimal wavelength is at 254 nm. At wavelengths of < 200 nm, ozone is formed; this increases the sterilization effect but is a health risk.

Chemical means. According to their reactions, chemical agents can be classified into the following groups:

- a) Protein-coagulating substances (metals or metallic salts, alcanole)
- b) Oxidizing agents (hypochloride, peracetic acid)
- c) Tensides
- d) Agents that react specifically with compounds

A clear separation of the agents according to their effect is very difficult, as they react in many ways (e.g., hypochlorides are protein coagulating and have an oxidizing effect). Most disinfection agents contain, apart from alkaline components, chlorine and oxygen, which have inactivation effects. The effectiveness of disinfection depends on the chlorine content of the agent of which the most common are:

- a) Hypochlorides (HOCl) decompose easily by splitting off oxygen and have a bleaching and very high disinfection effect. The most common agent is sodium hypochloride.
- b) Chlorinated lime (calcium chloride hypochloride), $\text{CaCl}(\text{OCl})$, does not have as strong a disinfection effect as sodium hypochloride and is used mainly for the disinfection of floors and wastewater containers.
- c) Chloramine-T (sodium *p*-toluenesulfochloramide) does not have the intense smell of chlorine and has a slow but long-lasting disinfection effect.

Other halogens, such as silica fluor acid $\text{H}(\text{SiF})$, are used in a few cases for disinfection. As halogens form salts when in contact with metals, there is a great risk of corrosion with these disinfection agents, although the approved agents have inhibitors. Therefore the indicated concentrations must be used. Another common disinfection agent is peracetic acid in a 40% stabilized solution.

Formalin, as a 40% formaldehyde-methanal solution, is no longer permitted as a disinfection agent. Lime is used as a disinfection agent for painted walls, and hydrogen peroxide (H_2O_2) is used in 15–30% solutions for disinfection of packaging materials. Within the group of metallic compounds only preparations with colloidal dispersed silver become significant in the disinfection of drinking water, with an application dosage of 10 g/ml.

Among tensides, the cation-active ammonium compounds (quats), which block the permeability of the cell membrane of the microorganisms, are mainly used.

Reaction of the disinfection agents. The inactivating effect on microorganisms is based on the following, mostly complex reactions:

- a) Blocking of cell membranes and therefore interruption of metabolism
- b) Coagulation of cell proteins
- c) Removal of some cell substances
- d) Irreversible damage of the cell physiology by cell toxins
- e) Disruption of the cell's osmotic pressure by water removal

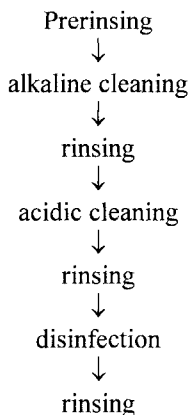
Depending on the reaction spectrum of the disinfection agents, we distinguish between

Against all microorganisms	microbicidal agents
Against bacteria	bactericidal agents
Against mold (yeast)	fungicidal agents
Against spores	sporicidal agents

Agents that inhibit the growth or propagation (react in a static way) are called bacteriostatic agents. A general antimicrobial effect is caused by heat treatment. Chemical agents react in the same way.

11.5. Cleaning and disinfection processes

These processes are based on the principles described in Sections 11.1 to 11.4. In many cases, processes must be designed, tested and modified in situ for the specific situation and requirements. However, the following principles remain the same for the basic operation and can be modified on a case-to-case basis:



The traditional dual-phase cleaning (in which proteins, fat and carbohydrates are removed by alkaline agents and mineral deposits and water hardness are removed by acidic agents) has been replaced today by single-phase cleaning (which can be followed by a disinfection process as in dual-phase cleaning). Under certain conditions, modern combined reagents can achieve a total cleaning effect.

Even in dual-phase cleaning, the acidic cleaning must be performed only when necessary (as with disinfection), as in many cases the alkaline agent, in conjunction with mechanical, physical means, can achieve both cleaning and germ reduction.

In Overview 11./1 a few of the processes are presented. In some cases, processes used during the manufacture of products, such as cleaning and disinfection of the transport facilities, bottles, buttering machine and the drying installation have been described.

Effectiveness of the solutions. The utilization efficiency of the solutions depends mainly on the load of fat and protein and the dirt load capacity, i.e., how well dirt is distributed in the solution. Multiple use of the cleaning agents CP and CAP is possible. Maximum utilization in cleaning is given as 100 cycles or 14 days.

- Solutions of the CDP and DP group must be prepared daily because of decomposition of disinfecting active groups.

When used solutions are added to fresh solutions, the cleaning effect is generally lower because of the dissolved dirt particles.

Check on cleaning efficiency. Mathematically, the cleaning and disinfection effect shows a logarithmic pattern, which means, among other things, that neither dirt nor microorganisms can be removed completely or completely inactivated.

Overview 11./1 Evaluation criteria for cleaning and disinfection efficiency

Cleaning object	Sequence	Means or type	Period min	Temperature In °C	Remarks
Heat exchanger and stainless steel pipelines in the circuit	Rinsing	Water	Until water is clear	15–30	The velocity of the cleaning solution must be double that of milk. After rinsing (5), the plate heat exchanger can be opened to relieve internal pressure
	Cleaning	CP or CDP ¹	30–40	70–75	
	Rinsing	Water	Until absence of alkali	70–75	
	Cleaning	CAP	20–30 until absence of acid	70–80	
	Rinsing	Water	10	10–20	
	Disinfection (before start-up)	Water	10	74	
Separator disks of non-self-cleaning centrifuges with washing machines	Cleaning	CP	20–30	60–100	Remaining residues must be removed manually with brushes
	Rinsing	Water	Until absence of alkali	60–80	
	Drying	Air			
Continuous buttering machine circuit	Rinsing	Steam		>100	Dissolution of butter residues Rinsing of the water-butter oil mix
	Rinsing	Water	Until clear discharge	50–70	
	Cleaning	CP or CAP	20–30	40–50	
	Rinsing	Water	Until absence of alkali	10–20	
	Disinfection	Water	10	75	Before start-up
Storage tanks	Rinsing	Water		10–20	
	Cleaning	CDP	10–20	50–60	
	Rinsing	Water	Until absence of alkali	10–15	
	Disinfection	Steam	10	>100	
Floors, tiles	Cleaning	CP brush or scraper	Until dirt is removed	40–50	
	Rinsing	Water	Until absence of alkali	10–20	

This is why after a cleaning and disinfection process the areas in contact with the product are checked using a contact sample to evaluate the residual population per cm².

¹ For definition of the acronyms, see Section 11.4.1.

For pipeline systems, the data of Table 11./1 are valid. Furthermore, if necessary, remaining dirt is determined and compared to the initial dirt by suitable methods.

In addition, many other visual inspections must be done, mainly for larger surfaces and for certain fittings. All stop, two-way and three-way valves as well as other similar installations, which have not been cleaned by CIP, must be dismantled after cleaning, steamed and reassembled after complete drying.

Table 11./1 Evaluation criteria for the cleaning and disinfection efficiency

Qualitative evaluation	Maximum tolerance in count/cm	Coliform bacteria in 1 ml of test solution
Good	≤ 5	negative
Acceptable	6–20	negative
Not acceptable	> 20	positive

Handling of chemical agents. To prevent accidents, the following principles must be adhered to when handling cleaning and disinfection agents:

- a) Liquid and powdered chemicals often have a caustic effect on the skin; therefore rubber gloves must be worn while handling concentrated reagents.
- b) When removing concentrated solutions from barrels, containers or bottles, protective eyewear, rubber gloves, rubber aprons and rubber boots must be worn. The containers must have suitable devices to permit risk-free removal, or pumps must be used.
- c) Concentrated solutions must be stored in a room, that can be locked.
- d) For treatment of possible burns, neutralizing agents have to available—e.g., 2% diluted acetic acid for treatment of caustic burns and a 1–2% NaHCO₃ for treatment of acid burns. Quick and extensive rinsing with water is also helpful for burns.

CIP (clean in place/circulation in place). In all cases in which there is a continuous flow process, circulation of the cleaning and disinfection solution (i.e., a so-called cleaning-in-place process) is possible.

- CIP is a process in which a cleaning and disinfection solution circulates in a circuit that does not need to be dismantled for this activity.

This process may also be called circulation cleaning, and in many cases it is an automatic operation. The following requirements must be complied with:

- a) Utilization of a control system, separate from the production control system
- b) Utilization of valves that prevent blending of product with cleaning solutions
- c) Design and conception of plants in such a way that all parts in contact with product are reached and covered by the cleaning solution
- d) Corrosion-resistant material for all parts in contact with the product

A CIP process is applied where there are circuits, e.g., storage tanks, process lines, milk production, butter section, cheese section, milk drying and others.

Operation of a CIP installation (Figure 11./3). The automatic cleaning process and its phases are controlled from a control panel (1). According the required cleaning protocol, a program can be started, that executes the cleaning steps as they are shown in Table

11./2. The cleaning program can be varied in time and sequence, in reality the following variants are selected in many cases:

- a) steps 1–10, working area, plate heat exchanger, storage tanks at certain times
- b) steps 1, 3, 5, 7, 9 working area, plate heat exchanger, storage tanks at certain times
- c) steps 1–6 cleaning of storage tanks
- d) steps 1, 3, 5 pipeline circuits

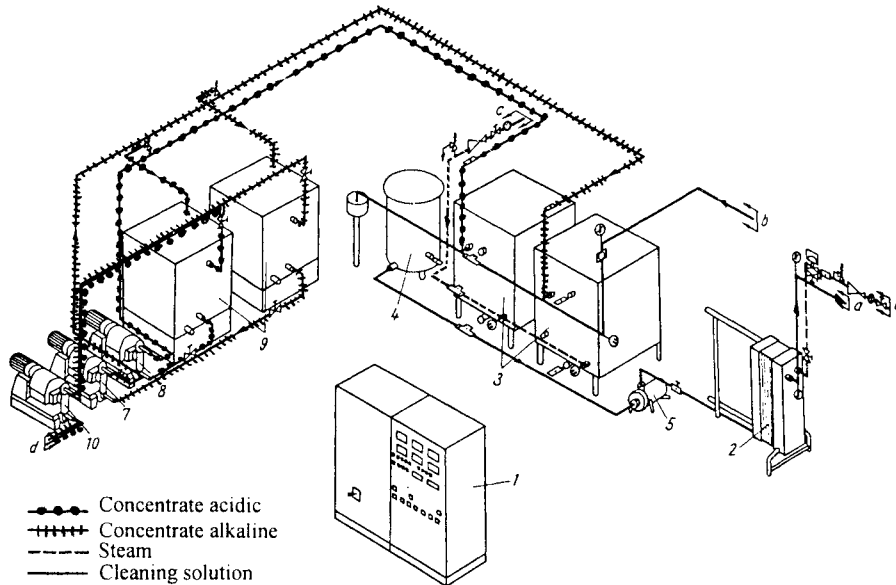


Figure 11./3 Process line for CIP

(1) Centralized control panel for automatic mode (2) Plate heat exchanger (3) Tanks for alkaline and acidic solutions (4) Buffer tank (5) Centrifugal feed pump (6) Centrifugal pump return flow (not included in drawing, is placed beside the tanks to be cleaned) (7) Membrane pump for alkaline concentrate (8) Membrane pump for acidic concentrate (9) Tanks for alkaline and acidic concentrates (10) Membrane pump for concentrate

After prerinsing with water and a short intermission, which is most often used to clean tanks, the cleaning phase proper begins, which corresponds to step 3 (caustic cleaning). For this, the cleaning solution from tank CIPT 1 (3) is transferred by a pump (5) to the plate heat exchanger (2) of the circuit. The concentration of the solution is controlled by electric conductivity in the tank containing the cleaning solution. (see 2.3.2.10). The conductivity is set on the controller of the control panel (1).

When the concentration is below the selected value, a cleaning agent concentrate is added from its container (9) by a pump (8). The temperature of the cleaning solution is indicated on the control panel and is controlled automatically. For this purpose a sensor is installed in the return flow pipeline to account for heat losses during circulation. Further, conductivity is determined in the return flow in order to have a clear separation between rinsing water and cleaning solution. The plate heat exchanger is heated with saturated steam and is also controlled automatically.

Step 7 (acid cleaning) is done in the same manner as step 3 except that only machines are operated used for acid cleaning.

The quantity of circulating cleaning solution is 20 m³ per hour at 3.5 bar, maximum 30 m³. The requirement for fresh water is up to 30 m³ per hour, steam up to 500 kg per hour, air up to 18 m³ per hour. The electrical load is up to 9.18 kW.

Table 11./2 Cleaning program

Cleaning step	Temperature in °C	Length of operation in min	
		Possible	Optimal
1. Prerinsing	30–40	1–15	3–5
2. Discharge		1–10	2–3
3. Caustic cleaning	70–90	1–60	15–20
4. Discharge		1–10	2–3
5. Rinsing	30–40	1–15	3–5
6. Discharge		1–10	2–3
7. Acid cleaning	60–80	1–45	15–20
8. Discharge		1–10	2–3
9. Rinsing	30–40	1–15	3–4
10. Discharge		1–10	2–3

11.6. Quality of utilized water

Water is the major agent for physical cleaning and is indispensable for the chemical cleaning because of its properties as a solvent and rinsing liquid. Therefore water must be free of pathogenic germs and must have drinking water quality. For other purposes, water does not need to have to have drinking water quality, but can have used water quality.

An important aspect is dissolved minerals in drinking water, which can vary with the season and region and can have a significant effect on the efficiency of the cleaning agent. Water-hardening agents bind caustic reagents, resulting in undesirable deposits on the treated surfaces. The chlorine content can result in precipitation of nearly insoluble acidic salts. Iron ions at high concentrations have a negative impact on the effectiveness of some cleaning agents. Water with a high content of carbonates and sulfates is not suitable for cleaning, as there will be encrustation on the cleaned surfaces.

12 Water Supply and Wastewater Treatment in a Dairy

12.1. Water supply

12.2. Wastewater treatment



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12 Water Supply and Wastewater Treatment in a Dairy

12.1. Water supply

12.1.1. Water requirements

In a dairy, large quantities of water are required on a daily basis for production and other technical purposes. The basis for the water requirement or water consumption is mostly 1000 l of processed milk; in some cases, the absolute consumption per day or per annum is indicated.

- Specific water consumption is on a level of 1000–5000 l per 1000 l of milk.

The actual requirement can vary between dairies and is a function of

- a) Manufacturing process or manufacturing profile
- b) Auxiliary processes such as steam generation, design of the refrigeration processes and extent of social services
- c) Multiple use/reuse

Water is a very valuable basic resource that belongs to all and is not available in unlimited amounts; it is therefore an important cost factor, which should lead to careful consumption. The water supply system in a dairy should be designed in such a way that consumption for each manufacturing department and auxiliary processes can be determined. This makes it possible to influence water consumption directly, and major losses can be determined very rapidly.

12.1.2. Water supply

Among other factors, uninterrupted operation depends to a large extent on constant availability of the required amounts of water. Therefore a water supply should always be assured. Dairies have the following supply possibilities:

- a) Own water supply
- b) Water supply from the municipal water system
- c) Mixed supply (own water and municipal water)

For self-supply of water, well water, ground water and/or surface water (with limitations) can be used. Self-supply often requires a considerable investment for the construction of installations (well, machines and treatment plants) and for a continuously controlled operation. In many cases water quantities from the self-supply system are insufficient to cover all requirements, and either a mixed water supply system or water from the municipal water system is required. A scheme for a mixed water supply is shown in Figure 12./1.

The self-supply and municipal supply are controlled by the authorities, and they also analyze samples from the plant.

With self-supply, water is normally pumped from a well into a storage tank or basin, which is kept covered (e.g., with earth) to keep the water cool. The capacity is equal to 1–2 days of consumption.

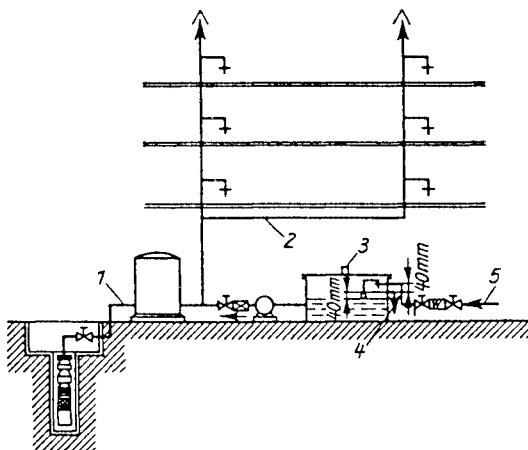


Figure 12./1 Scheme for a mixed water supply (self-supply and municipal supply)

(1) Own water system (2) Supply system (3) Aeration and deaeration (4) overflow (5) Connection to municipal supply system

12.1.3. Water quality

A dairy receives primarily fresh water, which must be of drinking water quality.

- Drinking water in its original or treated state is suitable for human consumption without any health risks; it is acceptable in taste, odor and appearance.

The standards for drinking water quality are shown in Table 12./1. Fresh water that has been used in heat exchange circuits for cooling purposes and has absorbed heat can be used as warm water, e.g., for cleaning purposes.

- Warm water is fresh water coming off from cooling installations.

Quality requirements depend on the utilization, whether water is used in production (as cooling water, water for cleaning, boiler feed water) or for social services (bathrooms, kitchens). Water used in a dairy must meet microbiological standards, so that germs do not have any effect on the manufacturing processes or on products. It must be free of inorganic or organic sediments and must be colorless. Certain requirements regarding temperature and chemical composition must also be met; organoleptic quality must be in line with that of drinking water.

Water for production purposes. This includes water that is in direct contact with or incorporated in milk or milk products. Examples are water for the production of long-shelflife products, for the manufacture of lactose, butter wash water, water for cheese production and water as a solvent for product preparations. This water must meet drinking water quality standards.

Cooling water. Cooling water that is used directly for cooling of milk and milk products must meet drinking water quality standards but can be used later as warm water for cleaning processes or in heat recovery circuits. However when surface water that does not meet drinking water standards is used for cooling purposes, it must be discharged as wastewater.

A special requirement for cooling water is that the hydrogen carbonate hardness should not exceed 6° (German hardness); otherwise sediments and incrustations can form on the walls of the equipment and inside the pipelines.

If cooling water is recirculated for heat recovery in open cooling installations, another aspect to be considered is that the original components in the water are concentrated by evaporation and are deposited on the heat exchanger surfaces.

Table 12.1 Drinking water quality standards for manufacturing purposes in a dairy

		Guideline	Maximum tolerance
Temperature	°C	8–12	≥3 and ≤20
pH		6.8–8.6	≥6 and ≤9
KMnO ₄	mg/l	≤12	20
Chloride ions	mg/l	≤250	350
Fluoride ions	mg/l	1.0	1.3
Potassium ions	mg/l	≤10	10
Sodium ions	mg/l	≤80	150
Calcium ions	mg/l	≤100	280
Total hardness	°	2–25	40
Carbonate hardness	°	2–25	25
Carbon dioxide	mg/l	0.4	
Oxygen, dissolved oxygen O	mg/l	610	≤4 and ≤14
Iron, total	mg/l	≤0.1	0.3
Dry matter	mg/l	1000	1500
Psychrophilic microorganisms	per ml	<50	100
Mesophilic microorganisms	per ml	<5	20
Pathogenic bacteria		absence	absence
Coliform bacteria		absent in 100 ml	absent in 100 ml

Water for cleaning purposes. Water used for cleaning of machines, installations, pipelines and storage tanks must also meet drinking water quality standards. If permitted by the authorities, used water can be utilized for cleaning purposes if:

- a) The original quality has been drinking water.
- b) It has been used only in closed circuits.
- c) Storage tanks for used water are closed.
- d) Used water from storage tanks has been chlorinated.

The objective is to utilize used water for all cleaning purposes in order to reduce fresh water consumption and to recover energy. For cleaning premises and streets, other types of water can be used.

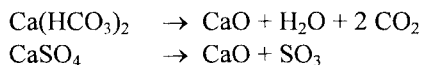
Boiler feed water. There are no hygienic requirements for water that is used in the manufacture of steam in boilers. An exception is the manufacture of “culinary steam” (e.g., for the UHT process in milk, where drinking water quality standards must be met). Boiler feed water does not have to meet the standards for nitrate and chloride content; however, hardness (carbonate and sulfate) must be very low (see Table 12.2).

Hardness in water is caused by dissolved calcium, magnesium and iron salts (especially hydrogen carbonates and sulfates). Total hardness of water is composed of temporary or carbonate hardness, Ca(HCO₃), and permanent or sulfate hardness, CaSO₄, MgSO₄. Carbonate hardness can be removed by boiling:



Sulfate hardness can be removed with chemical agents. Total hardness can be removed by different processes, such as the lime-carbonate process or a base ion exchange process.

Water hardness is indicated in degrees German hardness, where one degree hardness (1 °dH) corresponds to 1 g of dissolved CaO in 100 l of water. The amounts of dissolved calcium and magnesium salts are indicated in equivalent amounts of CaO.



Hardness level	1 - 8	8 - 16	16 - 24	above 24
Water type	soft	medium hard	hard	very hard

Table 12./2 Specification for boiler feed water (maximum values)

	Large steam boiler	Water tube and special boilers
Dry matter		300 mg/l
Nitrates		5 mg N ₂ O ₂ /l
Chlorides		200 mg Cl /l
KMnO ₄ consumption		as low as possible
Total hardness (German hardness)	1 °d (normal load) 10 °d (higher load)	0.1 °d
Alkali		0.4–2.0 g NaOH/l or 1.85–3.0 g Na ₂ CO ₃ /l
pH		8.5
Oxygen	1.0 mg O ₂ /l	0.05 mg O ₂ /l
Silicate		5 mg SiO ₂ /l for soft water
Oil	5 mg/l (normal load) 10 mg/l (higher load)	3 mg/l

In steam boilers and pipelines, hard water leads to the formation of stone (solid incrustations of calcium carbonate CaCO₃; magnesium carbonate, MgCO₃; and iron(III) hydroxide, Fe(OH)₃, which reduces the heat transfer from the boiler tubes to water. In certain cases it can lead to an overheating of the boiler tubes, cracks or even boiler explosions. Boiler feed water must always be softened before being used.

Water for social services. Water for social services and for kitchens (preparation of food) must have drinking water quality.

12.1.4. Water treatment

In order to meet the required water quality standards, water must be treated, especially in a self-supply situation. The extent of treatment is influenced by the type of water utilization and original water quality. Subject to the original water quality, treatment covers three phases:

- a) Removal of undissolved solids (organic, inorganic)
- b) Removal of dissolved solids
- c) Removal of microorganisms

Water treatment plants are normally required only for dairies that have a self-supply or a mixed supply system. Water from the public supply system has been treated to

drinking water quality standards. Water treatment can be done by several processes, which are described in the specialized literature. Membrane filtration is one of the suitable processes.

12.2. Wastewater treatment

12.2.1. Production and composition

Wastewater is characterized by the following criteria:

- a) Origin
- b) Composition
- c) Treatment potential
- d) Impact on environment

On a daily basis, large quantities of wastewater are present in a dairy. It consists of:

- a) Wastewater with milk components, consisting of cleaning water from milk process lines. The quantity is approximately double the quantity of the milk handled.
- b) Wastewater from social services, i.e., bathrooms, showers, and toilets as well as the kitchen. It amounts to 75 l per employee per day.
- c) Cooling water from milk cooling and refrigeration plants.

An overview of the wastewater composition is given in Table 12./3. In order to discharge (without problems) untreated water into a public wastewater system, the dairy wastewater, containing mostly organic matter, must be diluted by a factor of 150–200. As this does not make sense for a dairy (and is not permitted), treatment is required, i.e., clarification of the wastewater. Discharging untreated wastewater into public water system can lead to massive fish losses, as well as destruction of the biological self-cleaning (by microorganisms) in rivers, lakes and canals thereby resulting in major ecological damage.

Table 12./3. Composition of wastewater from different manufacturing departments (Kieferle)

		Milk reception	Butter dept.	Cheese dept.
Dry matter	g/l	1.5–6	0.4–7.5	1.2–16.2
Ash	g/l	0.5–1.1	0.3–2.1	0.4–2.9
Protein	g/l	0.2–1.0	0.02–2.9	0.4–2.0
Fat	g/l	0.3–1.1	0.1–0.6	0.3–0.5
Lactose	g/l	0.2–1.4	0.02–2.6	0.1–9.4
KMnO ₄	g/l	2.6–7.2	0.08–13.5	4.0–20.1
pH		8.3–10.1	6.5–9.7	4.3–7.9

In order to evaluate the pollution potential of wastewater and its negative ecological impact in an objective way, this risk is expressed in “damage units” (DUs) and has been calculated. Factors such as chemical oxygen demand and toxicity for marine life and microorganisms have been considered. Another parameter for the evaluation of wastewater is the required oxygen demand expressed as BOD and COD.

- BOD is the biological oxygen demand in mg O₂ required by microorganisms to decompose organic matter in 1 l of wastewater at 20 °C. BOD₅ is the oxygen demand for 5 days to complete the decomposition of organic matter in 1 liter.
- COD is the chemical oxygen demand in mg O₂ per liter required to oxidize organic matter in wastewater.

Sometimes both numbers are evaluated, and this is considered as the biochemical oxygen demand. If the level of carbohydrates and proteins is high, then the COD/BOD₅ ratio is > 1; if there is a high percentage of dry matter and cleaning agents in the wastewater, the ratio is < 1.

Other key indicators are the consumption of oxidizing agent KMnO₄ after 10 min reaction time for 1 liter, total organic carbon content (TOC) in mg carbon per liter, phosphorus content and especially nitrogen content. Maximum values are: for COD 110 mg/l, BOD₅ 25 mg/l, ammonium nitrogen 10 mg/l and phosphate 2 mg/l.

In Germany, many regulations have been established by federal and state authorities; a distinction is made between direct discharge (discharge of non-treated wastewater into the public system) and indirect discharge (discharge of pretreated or treated wastewater).

12.2.2. Wastewater treatment

In some larger municipalities with a high-capacity wastewater treatment plant, dairies can discharge wastewater directly into the wastewater system, but it can be safely assumed that treatment costs increase. Therefore assessments must be made for a partial or complete wastewater treatment.

For the treatment (cleaning) of wastewater, there are basically two processes, mechanical treatment and biological treatment. A combination of both is shown in Figure 12./2.

12.2.2.1. Mechanical treatment

Coarse and fine grids, sieves and filters retain dirt particles, which are then removed by scrapers and composted. The cleaning effect is increased when dirt has been precipitated with chemical agents. For this purpose, e.g., iron chloride or iron or aluminum sulfate is used, which specifically precipitates the proteins. Membrane filtration has gained some significance in wastewater treatment; polluting particles are not only separated efficiently but are fractionated and can therefore be used for specific applications.

12.2.2.2. Biological treatment

Biological wastewater treatment processes use specific effects that occur in nature without human intervention. Different kinds of microorganisms decompose soluble and colloidal organic matter and produce CO₂, H₂O, NH₄, PO₄, SO₄, CH₄ and biomass. The efficiency of the biological processes is controlled mainly by the available oxygen and the microorganisms; two different effects are involved:

- a) Aerobic effect. The microorganisms use dissolved oxygen for their metabolism. Heterotrophic¹ microorganisms decompose organic carbon compounds; autotrophic² organisms oxidize ammonium and nitrite.
- b) Anaerobic effect. Carbohydrate, fat and protein are decomposed in four stages in the absence of oxygen. Heterotrophic facultative anaerobic microorganisms and obligate anaerobe microorganisms cause hydrolysis and fermentation. Obligate anaerobic mi-

croorganisms produce acetic acid, and autotrophic hydrogen-oxidizing microorganisms produce methane as a biogas.

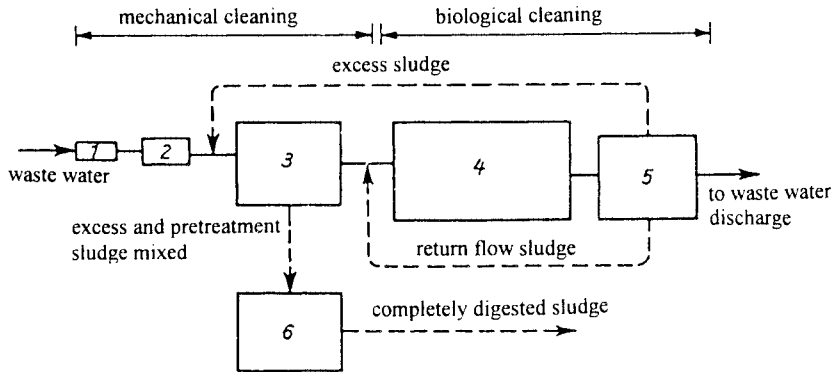


Figure 12./2 Basic scheme for a wastewater treatment plant (mechanical and biological)

(1) Grid (2) Sand basin (3) Pretreatment basin (4) Active sludge basin (5) Post-clarification basin (6) Decomposing basin

Furthermore, there is a so-called anoxic effect. In the absence of dissolved oxygen heterotrophic, mostly facultative microorganisms use oxygen bound to nitrates and nitrites for the decomposition of organic carbon compounds.

Anaerobic processes. Two processes should be mentioned, the activated sludge process and the droplet-lattice process.

Activated sludge system (Figure 12./3a). It consists of a large tank used as a bioreactor which has aeration devices (fans, jets, rotating brushes), a post-clarification basin and a sludge return flow. Wastewater, precleaned mechanically, flows continuously through a reactor, where activated sludge (containing the microorganisms) is suspended in the form of sludge particles. Large quantities of air are incorporated in the activated sludge, and metabolism can take place. The concentration of biomass is 1.5–5 g dry matter per liter liquid.

In the process, which is controlled very easily, a large amount of air expressed in kg O₂/l must be incorporated, resulting in a high electrical power requirement for the aeration devices. To control the metabolism, part of the sludge is recirculated into the reactor.

Droplet-lattice system (Figure 12./3b). This so-called solid-bed reactor is a large tank with a multi-layer water-permeable devices with a large surface that is completely covered by microorganisms and can be controlled easily. Wastewater is transferred to the top, is sprayed onto the surface and flows to the bottom. Nutrients are utilized by the microorganisms and are thus removed from the wastewater. Air flows from the bottom to the top through the lattice and supplies the necessary oxygen. A biological mass develops according to the airflow patterns and has a constant thickness, as part of this coating is continuously removed.

Post-clarification and sludge concentration is necessary, as for the activated sludge process; however, there is no sludge return flow.

¹ heterotrophic depend on organic material
² autotrophic depend exclusively on inorganic material

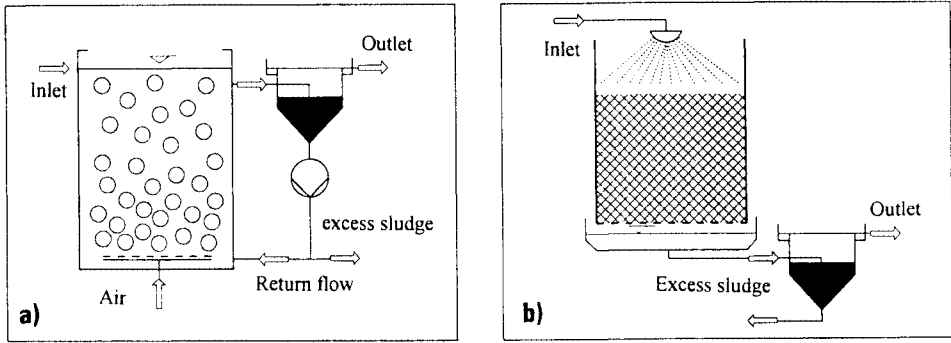


Figure 12/3 Aerobic wastewater treatment¹
 a) Activated sludge process b) Droplet-lattice system

¹Binder, H.: Biologische Reinigung hochbelasteter Abwässer der Lebensmittelindustrie; Deutsche Milchwirtschaft 7, 1994.

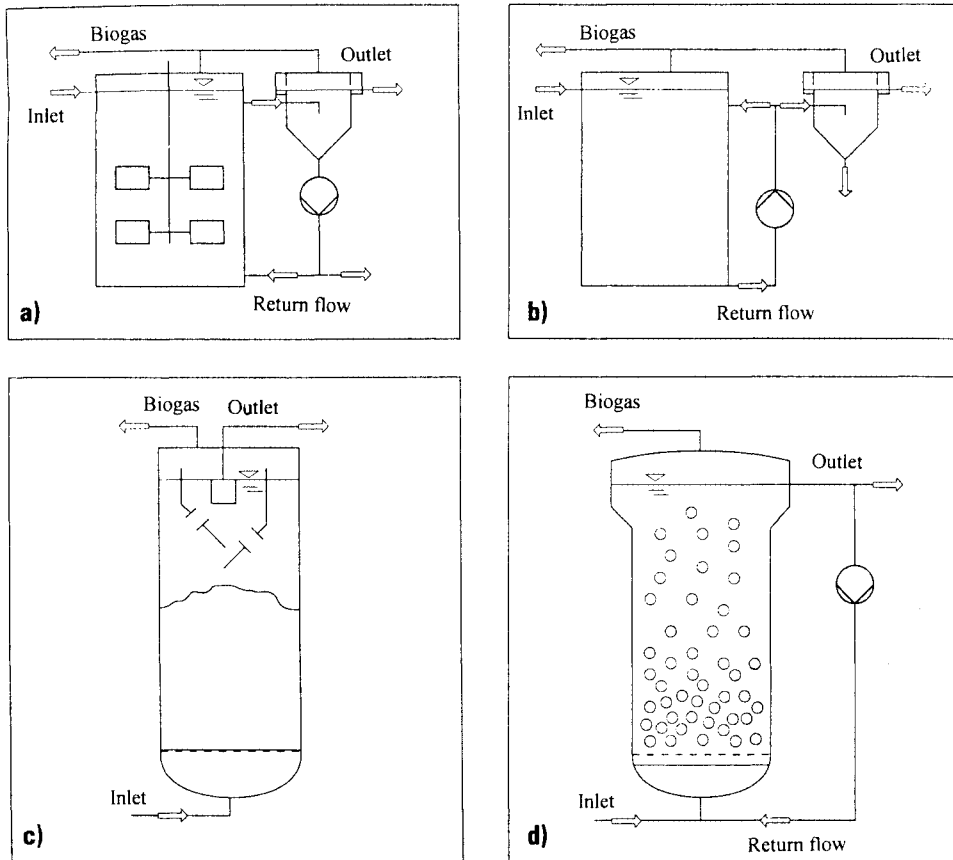


Figure 12/4 Anaerobic processes (see footnote to Figure 12./3)
 Anaerobe wastewater treatment in bioreactors
 a) Suspension reactor b) Solid bed reactor c) Sludge reactor d) Fluidized bed reactor

Anaerobic processes. Wastewater is submitted to a decomposing process in the absence of oxygen. A microorganism population works relatively slowly and must be adjusted very carefully to the wastewater load (concentration) and quantity, for which there must be a corresponding controlling technique (Figure 12./4). On the other hand, no energy is required for aeration, and there is only a small amount of biomass in the form of sludge. Biogas, which can be utilized, is also produced.



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13 Refrigeration in a Dairy

13.1. Terms

13.2. Refrigeration installations

13.3. Refrigeration and storage

13.4. Refrigerant distribution



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13 Refrigeration in a Dairy

13.1. Terms

In technical terms, cold means temperatures of ≤ 0 °C. In the physical-material sense this is heat which is measured in joule (J) or calories (cal, old dimension). The freezing point of water is the zero point on a thermometer and is known as an arbitrary setpoint. According to the Gay-Lussac law, the volume of any gas changes by 1/271.16 at 0 °C, if temperature is decreased by 1 °K at constant pressure. The absolute zero point is therefore -273.16 °C. A volume of 0 corresponds to an enthalpy of 0 and a temperature of 0.

- Cooling is the reduction of temperature by removing heat.

Any material or product can be used to cool another body, material or environment if its temperature is lower than that of the material to be cooled. Heat always goes from the warmer to the cooler material.

Milk and milk products are nearly always cooled artificially. Cooling is done in refrigeration installations, for which electrical energy is required.

13.2. Refrigeration installations

The basic principle of refrigeration installations is that evaporative heat or enthalpy (which is required for evaporating a liquid or cooling medium) is removed from an environment (material to be cooled) with a simultaneous cooling. Gas of the cooling medium that is created during evaporation has to be liquefied again in order to reevaporate in the cooling medium circuits.

Therefore cooling media with high enthalpy are selected, such as ammonia for industrial plants, rarely carbon dioxide, sulfur dioxide, freon, ethyl or methyl alcohol and for smaller plants mainly media free of halogenated hydrocarbons. For cooling medium circuits basically two systems are used:

- a) Compression refrigeration installations, where gas is compressed with a compressor and condenses during the cooling phase
- b) Absorption refrigeration installations, where gas is absorbed by water and is evaporated by adding heat

Absorption refrigeration units are used mainly for smaller units such as refrigerators. They are also used in larger industrial installations when large amounts of heat are available. In dairies, compression refrigeration units are most often used; a schematic is shown in Figure 13./1. It consists of four major elements, an evaporator, compressor, condenser and control valve, which are linked in a closed circuit by pipelines.

Principle. Liquid ammonia with a pressure of 3 bar is put into an evaporator, which is a system of tubes, and evaporates at -10 °C. Enthalpy is removed from the environment (room or the space around the tubes or a liquid flowing over the tubes), which is thus cooled down.

A compressor sucks the cold ammonia from the evaporator and recompresses it to 8–10 bar, and the gas temperature increases to 80–90 °C. In the condenser, the hot gas is

cooled by water (in smaller installations with air) to 20–25 °C and condenses, still at a high pressure.

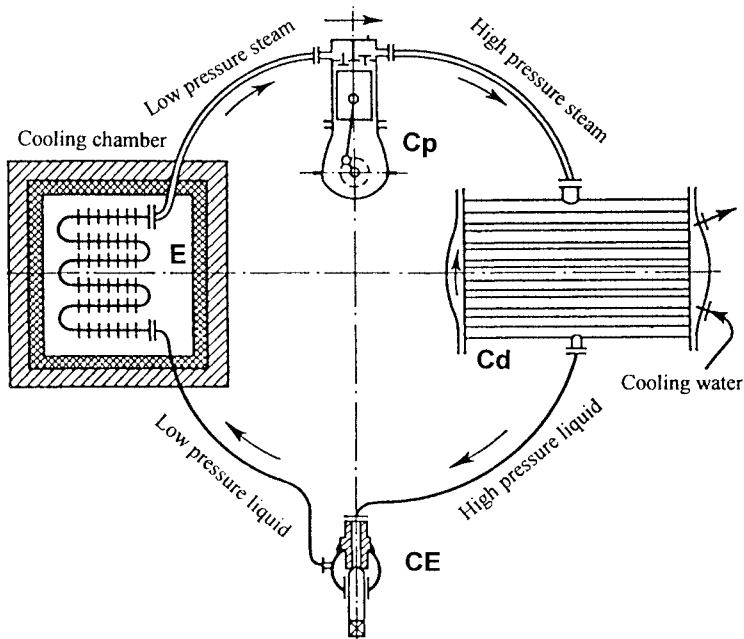


Figure 13./1 Scheme of a compression refrigeration installation

(E) Evaporator (Cp) Compressor (Cd) Condenser (CE) Control and expansion valve

The regulating valve, situated between the compressor and evaporator, permits passage into the evaporator of only amounts that it can decompress and evaporate, without equalizing the pressure between condenser (high pressure side) and evaporator (low pressure side). Temperature and pressure data and the type of energy involved for an ammonia compression installation are shown in Table 13./1.

Compression refrigeration installations can also be considered as heat pumps, as they produce heat of a lower temperature (cold) by applying mechanical energy.

13.3. Refrigerants and storage

- A cooling medium is a material that cools during evaporation while absorbing heat from the product to be cooled, i.e., there is a heat exchange.

Depending on how the heat exchange with the product (which is to be cooled) takes place, either direct with a refrigeration medium from a refrigeration installation to the environment of the evaporator or with a refrigeration medium (refrigeration carrier) we distinguish processes between processes involving:

- a) Direct evaporation
- b) Indirect evaporation

Table 13./1 Temperature, pressure and energy in a refrigeration plant

	Temperature in °C	Pressure in bar	Energy
Evaporator	- 10	2	requires heat
Compressor	- 10 to + 85	2 to 10	requires mechanical energy
Condenser	+85 to + 25	10	releases heat
Regulation valve	+25 to - 10	10 to 2	-

In a direct evaporation process (Figure 13./2) an evaporator is installed in such a way that it absorbs heat when it is in contact with the product to be cooled. During the cooling process the refrigeration installation must operate continuously; the refrigeration medium is the cold carrier.

If the cold carrier is stored in a central location, e.g., for operation of the compressors during the night (lower tariffs), a separate refrigeration medium is required. For this purpose, brine or water is cooled in an installation, and pumped to the product whenever required. Figure 13./3 shows refrigeration with an indirect evaporation.

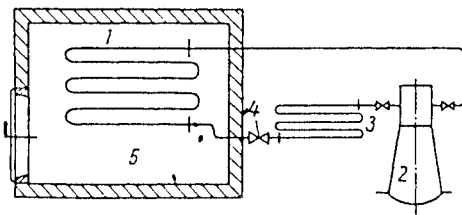


Figure 13./2 Direct evaporation
(1) Evaporator (2) Compressor (3) Condenser (4) Regulating valve (5) Cooling chamber

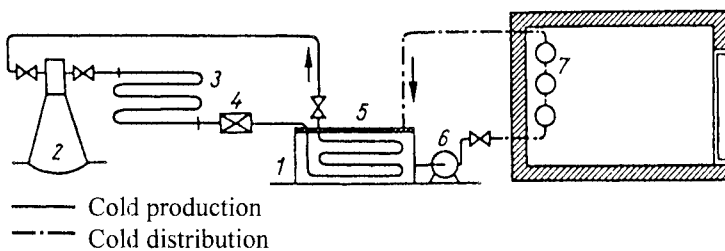


Figure 13./3. Indirect evaporation

Cold production: (1) Evaporator (2) Compressor (3) Condenser (4) Regulating valve

Cold distribution: (5) Brine in the evaporator (6) Brine pump (7) Brine pipeline system

13.3.1. Refrigeration with brine

- Cooling brines are salt solutions whose freezing point reduction is proportional to the molar concentration, i.e., the amount of dissolved material, and to the degree of dissociation.

Aqueous solutions of magnesium chloride $MgCl_2$, sodium chloride, $NaCl$, and calcium chloride, $CaCl_2$, are used. Brine can be quite aggressive toward metals, so 1 kg of bicarbonate is added per 100 l or 13 ml of hydrochloric acid. However, “noble” brines are available commercially that already contain an anticorrosive. Brine tanks and pipelines are usually made from plastic (PVC) in order to reduce the effects of corrosion.

The cold storage capability of brine depends on the volume as well as the temperature difference between the brine before and after utilization. It can be calculated as follows:

$$W = C \cdot \rho \cdot c(T_2 - T_1)$$

W cold storage capability as heat in kJ

C brine volume in liter

ρ specific gravity of brine in kJ/l

c specific heat of brine in kJ/kg °K

T_1 temperature after discharge in °C

T_2 temperature before discharge in °C

For maximal cold storage brine could be cooled to its freezing point. In reality, however, the brine temperature is not reduced below -10 °C in ammonia refrigeration installations, because the circulating refrigerant volume would be too low at a low evaporation temperature and the installation would not work economically. Therefore the brine temperature is reduced only to practical levels. Brine refrigeration has some disadvantages:

- a) Aggressive towards metals
- b) Risk of freezing in closed-loop coolers
- c) Significant losses in leaky pipeline systems
- d) Relative low storage capacity per kg of brine

Advantages are a high temperature differential between refrigerant and product to be cooled, a smaller heat exchanger surface and a smaller capacity of the storage container.

13.3.2. Refrigeration by ice water

Because of the disadvantages of brine cooling, in most cases ice water is used in dairies as a cooling medium for storage. The costs (compared to brine cooling) are 30–40% higher.

- Ice water is chilled fresh water with a temperature of ± 0 to ± 0.5 °C.

The advantages of ice water cooling are:

- a) No corrosion in the cooling water system
- b) High capacity
- c) No risk of freezing in closed-circuit coolers
- d) Negligible costs in case of leakage
- e) Efficient use of low electricity tariffs

Disadvantages are low temperature differences, higher flow rates through the cooling system and larger heat exchanger surfaces.

Ice water production. In a basin, adapted to the required heat capacity, tubes or plate heat exchangers are installed as evaporators and are totally immersed in water. Without circulating water, a 30–40 mm thick layer of ice forms on the tubes or plates. It is important that no ice blocks are formed and that water can circulate freely between the ice elements. The ice is frozen in three stages (Figure 13./4);

- Removal of heat from the liquid, i.e., cooling of water to 0 °C, i.e., 41.9 kJ/kg for water at 10 °C.
- Removal of melting heat/solidification heat of 335 kJ/kg without any temperature change
- Supercooling of ice to -3 °C, for which 6.28 kJ/kg are required (specific heat of ice is 2.09 kJ/kg °K)

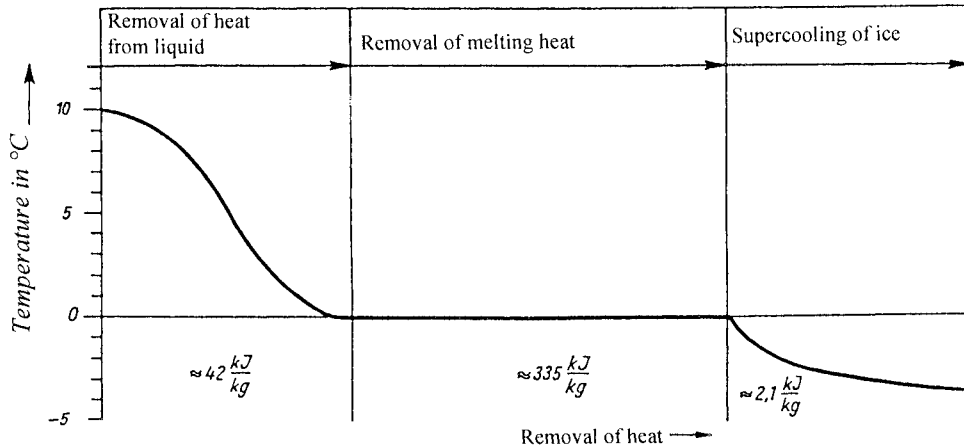


Figure 13./4 Heat removal during ice formation

- In order to convert 1 kg of water at 0 °C into 1 kg of ice, 335 kJ is required, i.e., in 1 kg of ice this amount of heat can be stored without a temperature change.

If water was replaced by brine, only -40 kJ/kg could be stored.

Economical aspects of refrigerant storage. Cold storage is of great economic significance for a dairy; therefore some energy and economical aspects are covered here.

Ice water plants account for about 30% of total electrical requirements and covering 80–100% of the total refrigeration requirement in the temperature range of > 0 °C in plants with refrigeration storage capability. Of the total electrical energy input 65% goes to the refrigeration plant and 35% to pumps and stirrers. Per ton of processed milk, 47–55 kWh is required for ice production. Zero to 85% of the total ice water demand is required between 0600 and 2200 h and 45% is required in the peak period (0700 to 1200 h). During this time a peak of 10–12% of the total energy requirement also occurs.

The ratio of the storage capacity of a plant to its daily cold capacity requirements control the costs for cold generation. If storage capacity is sufficiently large, ice water production and requirements can be separated on a time basis, which has a very significant economic effect (utilization of low tariffs during off-hours). Large ice water tanks, however, require higher investment costs.

- The energy optimum for cold storage capacity by ice water is 25–50% of the total daily requirements.

During the consumption of cold, ice water plants have to operate only pumps and stirrers; a stirring installation is necessary for constant water flow in the ice water basin and is the key to constant thawing of the ice. The following contribute to cost reduction for ice water consumption:

- a) Increase of the condenser surface in the refrigeration plant and utilization of condenser heat, e.g., heat pumps for heating purposes
- b) Adjustment of quantity of circulating ice water to actual consumption and avoidance of water losses
- c) Adjustment of ice water pressure to the different consumption locations

Ice water-based refrigeration can be designed without a storage basin. In this case smaller volumes of water are chilled in falling film or inclined film evaporators and are circulated immediately. However, during cooling of products, the refrigeration installation must be operated continuously.

13.4. Refrigerant distribution

In a dairy there are requirements for room cooling and for cooling of liquids. The requirements for the individual production departments can be very different, therefore heat flow for each department should be separate.

Room cooling. The most efficient type of room cooling is via direct evaporation. For this purpose, small automatically operated refrigeration units are used for individual rooms. They are sometimes located far apart, and their performance is adjusted to the room size. In these installations, freon or halogen-free hydrocarbons are used as the refrigerant. The evaporator is placed underneath the ceiling or on the wall, and a fan circulates air inside the room.

Sometimes dairies have rooms with indirect evaporation (in case brine cooling has to be used). Cooling with ice water is also possible. The cooling tube system is designed for large heat exchange areas by having fins attached to the tubes and can also be installed under the ceiling or on walls. Fans are again used for the circulation of air.

Refrigeration tubes covered with frost or ice must be thawed regularly, otherwise heat transfer is significantly reduced because of the low conductivity of ice ($\lambda=2.21 \text{ W/m}\cdot\text{K}$ vs. steel $\lambda=50\text{--}58 \text{ W/m}\cdot\text{K}$).

The main consumers are cold rooms for liquids and rooms for butter cooling, yogurt cooling, cheese ripening and general storage.

Cooling of liquids. During heat treatment of milk or cream, a significant cooling effect is achieved and considerable heat recovery of up to 90% is observed. In many cases fresh water cooling is used. Precooled products are then further cooled to 0–10 °C.

Cooling is done in plate heat exchangers and tubular heat exchangers, used for milk, liquid milk products, cream and paste products such as quark products, cream ripener and continuous butter machines.

In special cases, liquids can be cooled by direct evaporation in order to achieve good efficiency. For this purpose, tubular heat exchangers (evaporator) such as shown in Figure 13.5 are used, which require very good control to avoid freezing.

In order to avoid heat losses, all refrigeration pipelines are insulated. For this purpose, material with low heat conductivity is used such as cork ($\lambda = 0.38 \text{ W/m} \cdot ^\circ\text{K}$), Styrofoam ($\lambda = 0.02 \text{ W/m} \cdot ^\circ\text{K}$) or fiberglass ($\lambda = 0.41 \text{ W/m} \cdot ^\circ\text{K}$).

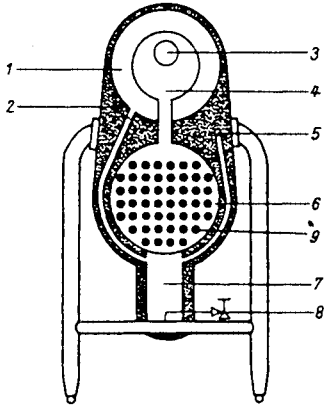


Figure 13./5 Tubular heat exchanger with direct evaporation (cutaway view)

(1) Compensation vessel (2) Rising or falling tube (3) Suction pipe (4) Liquid separator (5) Injection pipeline (6) Tubular cooler (7) Oil cup (8) Oil drainage (9) Product pipeline



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14 Energy Supply in a Dairy

14.1. Steam

14.2. Steam distribution and steam requirements

14.3. Hot water production

14.4. Heating and air-conditioning



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14 Energy Supply in a Dairy

14.1. Steam

Steam is produced by evaporation. During evaporation molecules with higher kinetic energy rise to the surface of water and pass into the gaseous phase (air), where the pressure of these molecules (steam pressure) is lower than the ambient air pressure. When temperature is increased, steam pressure increases, and if it has the same pressure as air, water has reached its boiling point (boiling temperature). For the transfer of the water molecules into the gaseous state (under these conditions), an additional amount of heat is required, the so-called enthalpy (heat for evaporation).

- To evaporate 1 kg of water at a pressure of 1.01 bar (1 at) and boiling point of 100 °C and convert it into steam, an enthalpy of 2.26 MJ is required.

Enthalpy is reduced at a higher temperature and pressure reaches 0 at the critical state of 374 °C and 220 bar; i.e., boiling water is immediately converted into steam. The following states of steam are known:

- a) Saturated steam or wet steam is produced, when no additional heat other than enthalpy is added. Then there is a dynamic equilibrium between identical numbers of evaporating and condensing molecules and a saturation equilibrium has been reached at saturation temperature and saturation pressure.
- b) Supersaturated or supercooled steam contains condensed water molecules and forms during slight cooling of the steam without complete condensation.
- c) Dry saturated steam or dry steam is available when all liquid molecules have been evaporated into a gas phase by adding heat. At the slightest temperature or pressure variation, it starts to condense and returns to wet steam conditions.
- d) Nonsaturated superheated or hot steam is produced when the temperature is increased beyond the state of dry saturated steam until the critical state is reached; before it can condense, its superheating energy must be removed.

For many heat exchange processes supersaturated or saturated steam is the most suitable state.

We will not describe how steam is produced. A separate professional certificate is required to operate boilers (high-pressure steam), and there are many different types of possible installations.

14.2. Steam distribution and steam requirements

In a dairy, heat is supplied mostly in the form of steam. For long-distance heat supply, hot water at elevated pressures and temperatures of 120–150 °C is converted into steam.

Steam distribution. Figure 14./1 shows a schematic of steam distribution and condensate recovery in a dairy. For individual areas there are different requirements regarding state and temperature. If steam is manufactured in situ, it is produced at 6–8 bars. For the operation of evaporators with steam ejectors 13 bars may be required, and when operating steam engines, 15 bars are required.

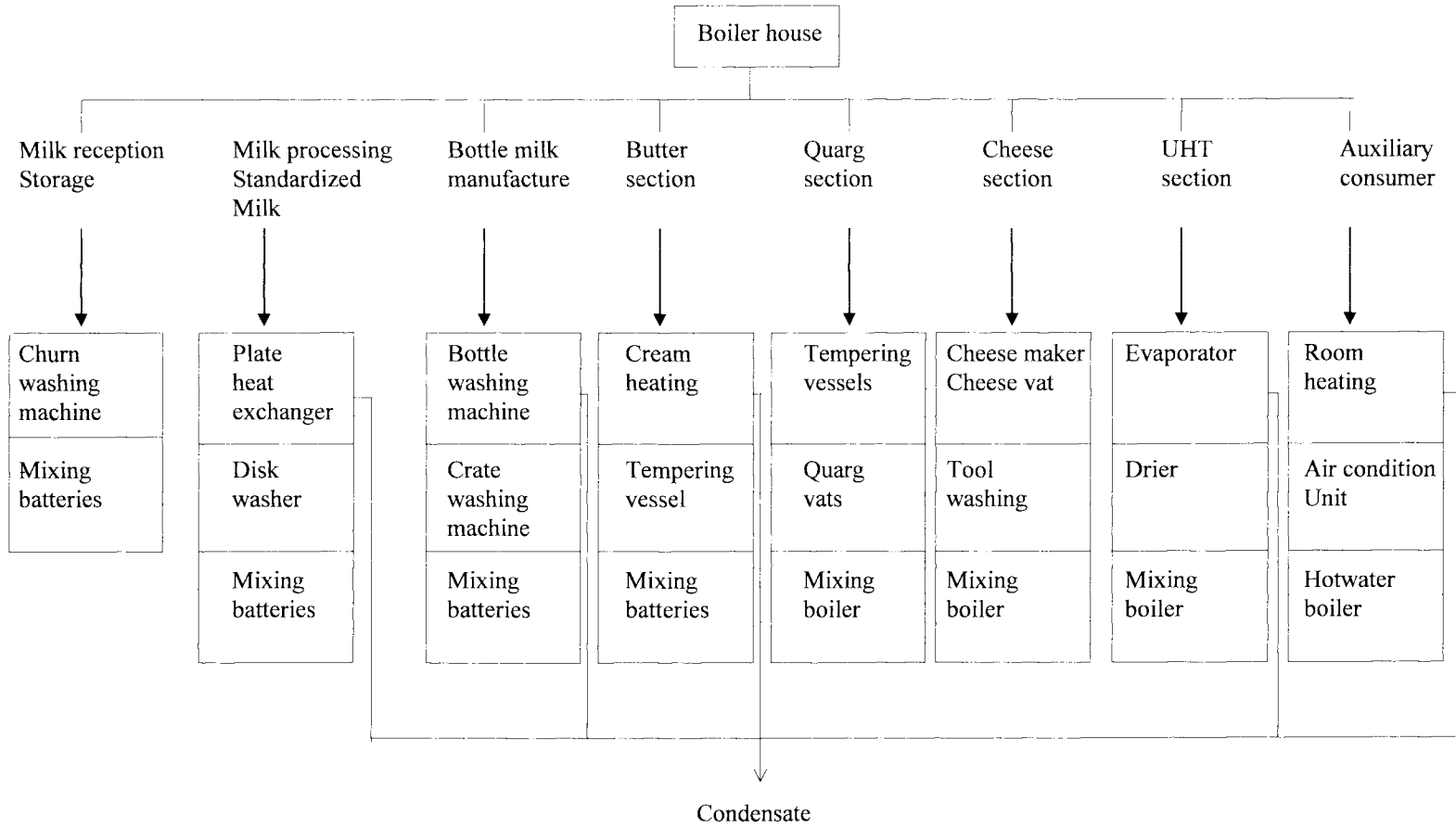


Figure 14./1 Scheme of the steam distribution in a dairy

The first steam distributor, which is a cylindrical tank with a volume of 150–200 liters, is located either in the boiler house or in most cases, immediately at the entry into the processing building. A regulating valve, which is installed before the distributor, reduces pressure to a standard operating pressure of 2–3 bars. From this distributor, steam pipes branch out to individual sections or to other distributors, and the supply line to the milk heating installations is the first to branch off. No others consumers are connected to this pipeline.

In order to produce the required wet steam for milk heating installations, a second regulating valve is installed between the distributor and heat exchanger, which reduces pressure to 1.8–2 bars (for indirect heating with hot water) and to 1.2–1.3 bars (for high-temperature heat exchangers in direct steam heating). The steam pipe between regulating valve and heater remains noninsulated and has larger dimensions, so that dry saturated steam can lose some of its enthalpy and be converted into wet steam. This cooling effect can also be achieved by injecting water into the steam pipeline, or water is sprayed or sprinkled onto the steam pipeline.

Steam requirements. The structure and manufacturing program of the factory controls steam requirements. It is a safe assumption to use 185–200 kg of steam per 1000 l of raw milk for total requirements. Exact determination of the individual consumers contributes in optimizing steam consumption.

14.3. Hot water production

Hot water is used mainly for manual cleaning and in social services facilities. The hot water can be produced in hot water boilers or in mixing batteries. Hot water boilers are cylindrical closed steel vessels that are installed in a horizontal position, and are fed with warm water or fresh water (for the social services section). For heating of water, the boiler has a tubular piping system through which steam passes. Water passes first through a pressure vessel—where the necessary operating pressure of 1–2 bar is created—an then through its own system to the places where it is consumed.

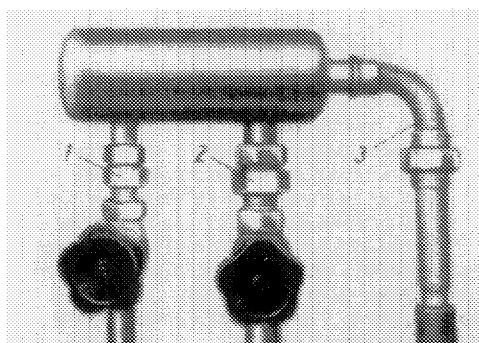


Figure 14./2 Mixing battery for the production of hot water
 (1) Steam supply (2) Cold water supply (3) Hot water discharge

Mixing batteries (Figure 14./2) are small steel containers that are installed directly in the place of consumption. There steam and water (fresh or warm) are directly mixed, and the required temperature can be set. For operating mixing batteries, the following aspects must be considered:

- | | |
|----------|--|
| Start-up | First open the water supply valve, then the steam supply valve. |
| Shutdown | First close the steam supply valve, then the water supply valve. |

In most dairies, hot water for production areas is produced in mixing batteries; for the social services section it is produced in boilers.

14.4. Heating and air conditioning

The purpose of heating is to warm up production, administration and social services rooms so that personnel employed there feel and perform well and their work is not impeded. In dairies many different heating systems are used which, depending on their type, can be used in combination, as described hereafter.

Heating with air heaters. A tubular or plate heat exchanger is installed in steel housing. A fan sucks room air, passes it over a heat exchanger, and blows it back into the room at a higher temperature. Louvers in the air outlets can direct the flow of air. Heating is used mainly for production and storage areas.

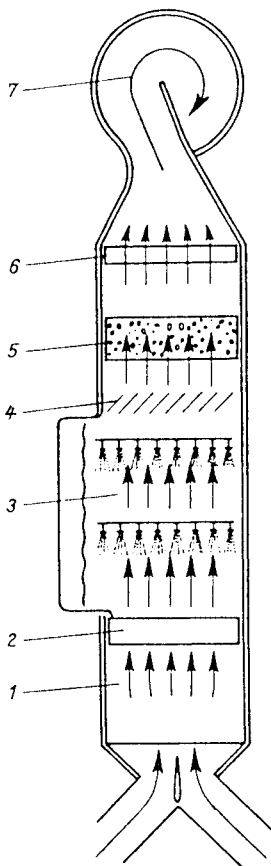


Figure 14./3 Installation for air conditioning (schematic)

(1) Mixing chamber (2) Air cooling (3) Air cleaning (4) Guiding vanes (5) Microbiological filter (6) Air tempering (7) Fan

Steam heating. Wet steam or dry saturated steam passes through a pipeline system and transfers its enthalpy to the environment. Air heating and circulation are done by convective flow, and heat exchange surfaces can be kept very small. This type of heating is rare and is used only in rooms where a high temperature with low relative humidity is required. It is not suitable for administrative or social services rooms, as dust can burn on the heating pipes and cause a bad room odor.

Warm water heating. Warm water with a temperature of 60–80 °C passes through heat exchangers with a large surface, which are part of a central system. Circulation is done with pumps or is based on gravity flow. Room air is heated by convective flow, and relative humidity can be controlled by attaching small water pots (most often made from ceramics).

Air conditioning. Very effective heating and air conditioning for production and storage rooms can be achieved with air conditioning units. In these units, air and humidity can be controlled too. Figure 14./3 shows schematically an air conditioning unit, from which air passes through a ducting system, most often installed underneath the ceiling, via fans to the rooms and is distributed there with suitable devices.

An air conditioning system can also have a cooling system in order to lower room temperature whenever required.



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15 Electricity in a Dairy

15.1. Electrical motors

15.2. Electrical energy requirements



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15 Electricity in a Dairy

15.1. Electrical motors

All machines in a dairy are equipped with individual electric drives; i.e., to perform work, one or more electric motors are integrated into a machine. The energy requirement varies from 0.5 to 20 kW; and in some cases is far more. Motors are very precisely defined in their performance (within narrow limits), unless their speed and performance can be varied by special options such as frequency control.

In automated processes, numerous control drives are used, such as thyristor control of valves, whose energy requirement is < 0.5 kW. For lower requirements, alternating current motors are used; for requirements above 1 kW three-phase current motors are used. The most common motors are asynchronous motors, where a current-free anchor runs after the rotating magnetic field, which is formed by a periodic changes of a three-phase current. Asynchronous motors are different only in type and circuitry. There are short-circuit motors and sliding ring motors, with the former more commonly used. In a few cases, e.g., for variable output control, direct current motors are used.

Electrical motors in dairies must meet very high safety standards. Motors in production areas must be protected against foreign objects with a diameter > 8 mm, against contact with tools, and against water (jet); therefore they are usually built in an encapsulated form. The acronym corresponding to the type of protection is indicated on the performance plate of the motor.

In order to avoid overload, each motor has a safety switch, usually found in a location other than the motor, which interrupts the power supply. Control of the motors is normally done manually from a central control panel or from a process controller.

Performance factor $\cos \varphi$. The performance factor is the quotient of actual performance to apparent performance. From the trigonometric function we can see that for a phase angle $\varphi = 0$, $\cos \varphi = 1$. If the two sinusoidal curves of two alternating currents reach their zero value and peak value at the same time, they are phase identical; if not, there is a phase delay. When phase angle φ increases, $\cos \varphi$ becomes < 1 . The smaller $\cos \varphi$ is, the lower is the actual current and the actual performance; i.e., the absorbed current and performance are not totally converted. The difference from the actual current and actual performance is the so-called blind current and blind performance.

A low performance factor occurs, when a motors or transformers are underloaded, and $\cos \varphi$ decreases. Motors must be adapted to the performance of the machine, and they should not be oversized. The blind current can also be compensated by the installation of blind current compensators.

15.2. Electrical energy requirements

Energy is normally supplied from a public utility system. Emergency power units, driven by diesel motors, are used to continue operations during disruptions of the utility system. In the reception stations of the plants are transformers that transform the incoming voltage of 380 volts to an operational voltage of 220 volt.

- Access to transformer stations is permitted only for authorized personnel.

Electric energy requirements in a dairy can be very different for the various production sections and auxiliary units and are characterized by the manufacturing profile. As a base value, 15–18 kW per 1000 l of processed raw milk can be assumed.

Energy peaks. Power requirements are very inhomogeneous, as the daily production schedule is never constant. As a result there are peak demand periods with extremely high energy requirements, which sometimes can happen for only a few minutes. For example, that asynchronous motors always have to run at full load in order to start the moving masses of a machine to its required performance or speed, and they therefore require a very high current.

If all motors started simultaneously at start-up, the peak would be so high that the main safety switch would interrupt the energy supply to all motors. Therefore, during start-up, motors should start in a defined sequence, and demand should be distributed evenly throughout the day. One of the key objectives should be to use the lower electricity tariff during nighttime, i.e., running the energy-intensive refrigeration compressors for cold storage during the night.

16 Hygiene and Occupational Safety



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16 Hygiene and Occupational Safety

- Hygiene is the science of maintaining and improving health and preventing and eliminating diseases.

It can be separated into two parts: human hygiene and animal hygiene. Both fields are important for the dairy industry. Key aspects are labor, construction, operational, nutritional, food, school and social hygiene.

- Occupational safety covers all activities and means that contribute to protecting the life and health of the working population, maintaining their working capabilities and designing work in an ergonomic way.

Occupational safety therefore includes protection against professional sicknesses and fire; safety and functionality of workplace, machines and installations; and first aid. Protection of the workforce is governed by federal regulations (laws, ordinances) as well as regulations of insurance institutions and professional associations, which are important. The basic structure of occupational safety is shown in Figure 16./1. In many cases, careless attitudes and work habits contribute to accidents. Each employee should therefore know and respect the following basic rules:

- Workers should be well rested and attentive. Alcohol consumption during work is prohibited.
- Before work is started for the first time or at a new workstation, there must be instruction on prevailing safety rules.
- Wear the required protective and hygienic clothing. Keep it well.
- Teasing and fighting at the workplace leads to accidents in many cases.
- Even for minor injuries, report to the first aid section, and report the smallest accident to your superior.
- If risks and hazards have been recognized, they must be reported immediately to the next superior.
- Be a model for compliance with safe work practices. Keep helping to train other employees.

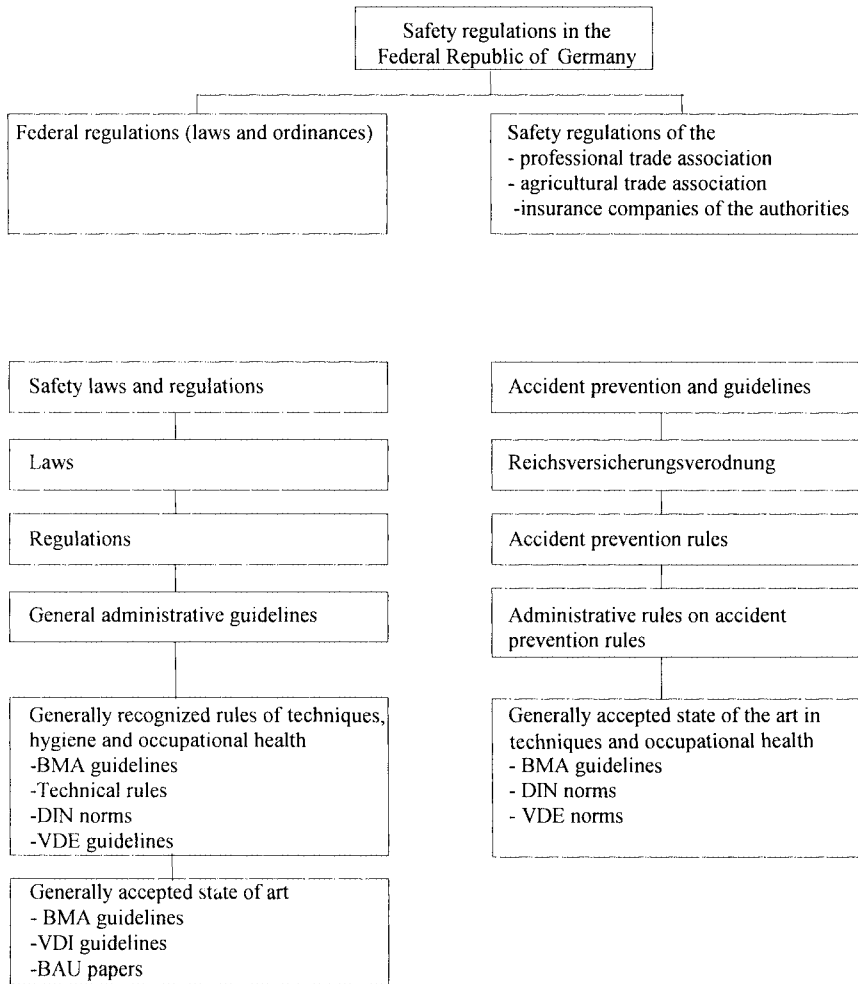


Figure 16./1 Basic structure of occupational safety instructions in Germany

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