CHEESE TECHNOLOGY GUIDE

SECOND EDITION

Tetra Pak®
PROTECTS WHAT'S GOOD

CONTENTS

MILK

Composition of milk

The composition of milk varies considerably between different animals. However, only milk from certain animals like cattle, sheep or goats can be used with good results for cheese production.

The majority of the world's cheese is made from cow's milk. The composition of cow's milk is influenced, among other factors, by feed, breed and stage of lactation. The two main types of protein in milk are casein and whey proteins. Native cow's milk also contains bacteria. Most milk in the world is produced by Holstein breeds.

Cow Breeds	Holstein	Jersey	Guernsey	Ayrshire
Fat	3.3	5.7	5.3	3.8
Protein:	2.8	3.7	3.6	3.1
- Casein	2.2	3.0	2.9	2.5
- Whey	0.6	0.7	0.7	0.6
Protein / fat ratio	0.85	0.65	0.68	0.82
Lactose	4.6	4.8	4.8	4.9
Ash	0.6	0.8	0.8	0.7

Table 1. *Approximate compositions of milk from different cow breeds.*

The size of the dry matter components of milk vary in size. Salts have the smallest diameter, while fat – present in globules – and bacteria have the largest diameters.

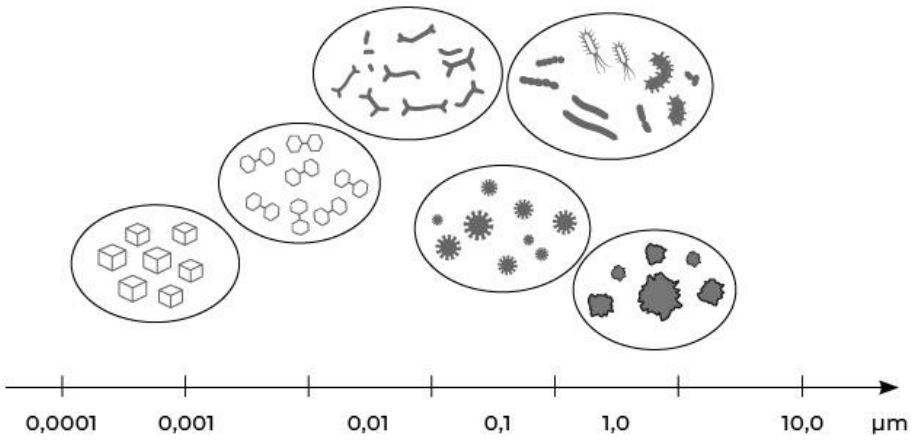

Figure 1. *Size of dry matter components in milk.*

Determination of milk composition by infrared milk analysers

Milk composition is analysed for fat, protein, lactose and water, and can be done by infrared milk analysers. One of the most used instruments is the MilkoScan (FOSS Analytics, Hilleroed, Denmark). In the instrument, the sample is diluted and homogenized. The mixture then passes through a flow cuvette where the components are measured by their infrared absorption at specific wavelengths.

- Fat at wavelength 5.73 µm
- Protein at wavelength 6.40 µm
- Lactose at wavelength 9.55 µm

The content of water is calculated on the basis of the sum of the values for fat, protein, and lactose plus a constant value for mineral content. The instrument requires exact calibration and must be thermostatically controlled.

Density of milk

The density of milk is correlated with the composition. The usual range is from 8.58 to 8.64 pounds/gallon (1.028 to 1.035 g/mL) for milk. Increased amounts of proteins and lactose increase density, while an increased amount of fat decreases the density value. Thus, cream has lower density than skim milk.

Density changes widely with the temperature, thus all measurements have to be made at the same temperature (usually 60°F/15°C), for results to be compared.

Fat (%)	Non-fat solids (%)	Density (lbs/gal)	Density (g/ mL)
3.0	8.33	8.61	1.031
3.5	8.60	8.60	1.030
4.0	8.79	8.59	1.029
4.5	8.95	8.58	1.028
5.0	9.10	8.58	1.027
20.0	7.13	8.43	1.010
30.0	6.24	8.36	1.002
40.0	5.35	8.17	0.992

Table 2. *Density of milk and cream at 15°C.*

Freezing point

The freezing point of milk is a reliable parameter to check if the milk has been diluted with water (i.e. adulteration). The freezing point of milk from individual cows has been found to vary from 30.94 to 31.03°F (-0.54 to -0.59 °C).

Adulteration with water causes the freezing point to increase.

The composition of milk can alter due to physiological or pathological causes (e.g. late lactation and mastitis, respectively), it is termed abnormal milk.

The most important change is a fall in lactose content and a rise in chloride content, but the freezing point remains constant.

Fat in milk

The fat in milk is present in fat globules with a diameter of 1 - 20 µm (0.001 - 0.02 mm). Because the fat globules have a lower density than the other constituents of milk, they can be separated by centrifugation. Homogenization gives a mechanically hard treatment to milk, causing the fat globules to break into smaller fat globules.

During cheesemaking, the fat globules are incorporated into the cheese. Milk is not homogenized before production of the majority of cheese types. Only a small number of cheese types, for example some blue cheese types, are made from homogenized milk.

Proteins in milk

There are two main types of milk proteins – caseins and whey proteins. Caseins are assembled in particles (i.e. casein micelles) with an average diameter of 100 nm (0.0001 mm) while the whey proteins form structures with a size of 1 - 2 nm. Thus, whey proteins are small and can easily be separated from caseins by microfiltration.

Caseins form the backbone structure in cheese and largely contribute to cheese texture. Most cheese types do not contain any whey proteins. In most cheese processes, whey proteins are separated from caseins during curd making.

Note that the casein content, rather than the total protein content, is the critical parameter with respect to cheese yield. Cheesemakers are therefore advised to regularly monitor the relative amounts of casein, whey proteins and non-protein nitrogen in their milk.

Acidity of milk

The acidity of a solution depends on its concentration of hydrogen ions [H+] and hydroxyl ions [OH–]. When the concentrations of [H+] and [OH–] are equal, the solution is called neutral. The pH is verified from the activity of hydrogen ions [H+] in a solution. When the pH is:

- Lower than pH 7 - The solution is acidic.
- pH 7 - The solution is neutral.
- Higher than pH 7 - The solution is basic or alkaline.

Native cow's milk is slightly acidic (pH 6.7). Many other foods have a lower pH. The pH of yoghurt and cheese is lower than milk.

A difference in pH value of 1 represents a tenfold difference in acidity, i.e. pH 5.5 shows a degree of acidity ten times higher than pH 6.5.

Acidity can also be reported in the titratable acidity (TA). This is based on different measurement methods in which the total content of free and bound acids is determined.

The titratable acidity of fresh milk is 17 (Thörner degrees, °Th), 7 (Soxhlet-Henkel degrees, °SH), 15.5 (Dornic degrees, °D) and 0.155 (percent lactic acid,% LA). This is equivalent to an approximate pH of 6.7.

In milk, it is the pH value – and not the titratable acidity – that controls the processes of rennet coagulation, enzyme activity, bacteria growth, reactions of colour indicators, taste, etc.

For most process-control purposes, pH is a more useful measurement than titratable acidity. Many cheesemakers, however, still use titratable acidity to monitor initial acid-development during the first hour after adding the starter culture. For this purpose, titratable acidity is a more reliable indicator because relative to pH measurement, it is more sensitive to small changes in milk acidity.

Measurement of pH with pH-meter

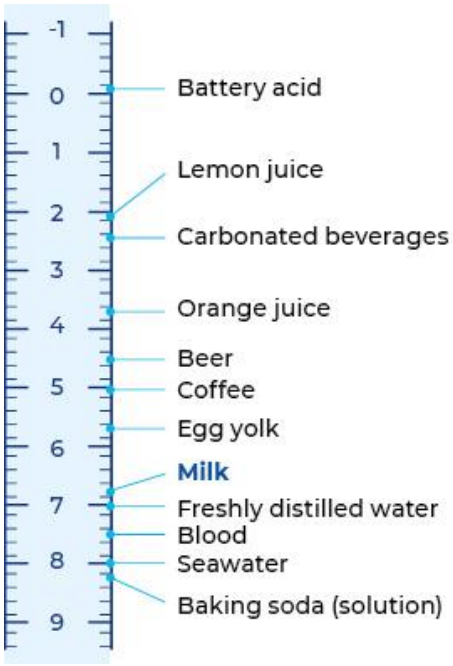

Figure 2. *The pH of milk and other common fluids.*

The pH value is measured by a pH-meter with a combined glass electrode. The system must be carefully calibrated before use.

Determining acidity by titration: Titratable acidity (TA) of milk is indicated by the number of mL of a sodium hydroxide (NaOH) solution required to neutralize 100 mL of milk, using phenolphthalein as an indicator. sodium hydroxide solution is added to the milk until the colour of the liquid changes from white to a uniform pale red.

Titratable acidity can be expressed in a variety of units depending on the strength (Molar or N) of the sodium hydroxide solution used for titration.

Method/Unit	Milk volume (mL)	Strength NaOH (Molar or N)	Traditionally applied in
Dornic degrees (°D)	100	1/9	Netherlands, France
Per cent lactic acid (% LA)	obtained as °D with the result divided by 100		North America, Oceania, UK
Soxhlet-Henkel degrees (°SH)	100	0.25	Central Europe
Thörner degrees (°Th)	100 (+200 mL water)	0.1	Northern Europe

Table 3. *Methods for measuring titratable acidity, including the amount of milk used for titration with sodium hydroxide (NaOH).*

When the acidity of cream is determined, the fat content has to be taken into account. For example, if the cream contains 38% fat and 10 mL of sodium hydroxide solution was used for 100 mL of cream, its acidity (°Th) is calculated in this way:

10 x [100 / (100-38)] = 16.1.

Preservatives and antibiotics

The growth of lactic acid bacteria may be inhibited by the presence of ordinary antiseptics or antibiotics in the milk. Rapid tests for determination of antibiotics – especially penicillin – in milk have been developed. The Dutch Delvotest P tests for penicillin, takes 2.5 hours and can detect penicillin concentrations down to 0.06 IU/m.

TREATMENT OF MILK FOR CHEESEMAKING

Separation and clarification

Centrifuges can be used to separate cream and skim milk. Under the influence of centrifugal forces, the fat globules (i.e. cream), which are less dense than the skim milk, move inwards toward the axis of rotation and leave through a central outlet. The skim milk will move outwards and leave through an outer outlet.

During clarification, dense solids like dirt, epithelial cells, leucocytes, corpuscles, bacteria sediment and sludge are separated from the continuous milk phase by centrifugal forces. In modern centrifuges, separation of cream and clarification are done continuously and at the same time in one centrifuge. The dense solids are collected at peripheral discharge slots.

Bactofugation and microfiltration are process/technics used for removal of spores and bacteria. Both processes are used to remove a higher number of spores, which otherwise can reduce the cheese quality. This is an issue most related to cheese type. In Cheddar cheese production, for example, salt is added directly.
Salt concentration, in combination with a low moisture level, prevents the growth and development of spores. On the other hand, the most sensitive cheeses are those with propionic acid fermentation, as they include a ripening stage at a high temperature (circa 18 – 22°C). These days, Gouda-type cheeses are also sensitive because there is a trend towards lower salt levels, which in combination with moisture level, makes cheese sensitive to the development of spores.

Bactofugation removes 95% of spores and is a centrifugal process that uses higher forces than separation. Microfiltration achieves a roughly 99% reduction of spore-forming bacteria. The spore-dense milk phase from bactofugation and microfiltration is UHT treated and added back to the milk.

Standardization

Standardization refers to the practice of adjusting the composition of cheese milk. Standardization will normally take place automatically before heat treatment to avoid subsequent contamination. The standardization of cheese milk has three separate objectives:

- To maximize economic return from the milk components and the cheese-plant investments.
- To maintain consistent cheese quality despite changes in the composition of raw milk.
- To meet cheese composition specifications. Specifications can be self-imposed (e.g. low-fat cheese) or imposed by government standards for specific cheese types.

Standardization of cheese milk normally requires increasing the protein/fat-ratio.

The fat content is decreased by first separating the whole milk into skim milk and cream by means of centrifugal separation. The right amount of skim milk and cream is then mixed to obtain the required fat content of the cheese milk.

The whey from the cheesemaking process also contains a small amount of cream, which can be separated and used in the standardization process of cheese milk.

The protein content can be increased by separation (i.e. membrane filtration) of water from the skim milk, which is later mixed with cream. A second option is to add protein, like skim milk concentrate or low-heat skim milk powder, to the cheese milk.

Because fat and protein contents vary between cheese types, the protein/fat-ratio in cheese milk has to be adjusted. To increase the capacity of the cheese plant, the cheese milk should have a high total solids content, but the protein/fat-ratio should be constant. However, if the total solids content of the cheese milk is too high, the cheese quality will change.

Cheese type	Cheese milk protein/ fat ratio	Cheese moisture (%)	Cheese fat (%)	Cheese fat in dry matter (%)
Cheddar	0.91	39	31	50.8
Colby	1.03	42	29	50.0
Monterey	1.04	44	28	50.0
Gouda	1.07	43	28	49.1
Edam	1.50	46	22	40.7
Emmental	1.13	40	27	45.0
Havarti	1.19	50	23	46.0
Pizza cheese	1.42	48	20	28.5
Pizza cheese (part skim)	2.20	48	15	28.8
Feta	0.90	55	22	49.8
Tvarog	4.12	74	5	19.2
Paneer	0.84	54	23	50
Cottage cheese	Skim milk	Curd is mixed with “dressing” (cream or non-fat)		

Table 4. *Guiding values for protein/fat ratio in cheese milk when producing common cheese types.*

Heat treatment

Heat treatment is applied to cheese milk in order to avoid public health hazards arising from pathogenic microorganisms in the raw milk. The process also increases the shelf-life of the final cheese product. However, cheese can also be made from raw milk that has not been heat treated or undergone thermization.

Heat treatment	Temperature	Holding time	Purpose
Pasteurization	146°F / 63°C 162°F / 72°C	30 min. 15 sec.	Inactivate and kill pathogenic bacteria
Thermization	145 - 149°F / 63 - 65°C	15 sec.	Prevent raw milk spoilage by acid or protease-producing bacteria
No	-	-	Results in raw milk cheese which has more flavour

Table 5. *Main types of heat treatments for cheese milk.*

In most countries, regulations require that cheese milk is pasteurized. The pasteurization is intended to only create minimal chemical and organoleptic changes; however, pasteurization inactivates enzymes, which contribute to the aroma-development during cheese ripening.

To create optimum conditions for cheesemaking, cheese milk is pasteurized just before the actual cheesemaking. If the raw milk has to be stored (cold) for more than 24h before cheesemaking, there is a risk that certain bacteria will spoil the raw milk. To prevent spoilage during cold storage, thermization is applied. Thermization only kills certain bacteria, and afterwards the milk is still classified as raw milk.

To minimize the risk of failure in the pasteurization process, the system is equipped with an automatic control system for:

- Pasteurization temperature. The flow is diverted back to the balance tank if the pasteurization temperature is below legal requirement.
- Holding time at pasteurization temperature. The flow of milk is diverted back to the balance tank if the holding time decreases.
- Pressure differential control. The system will activate the flow diversion valve if the pressure on the raw-milk side of the regenerator exceeds a set minimum below the pressure on the pasteurized side. This prevents possible leakage of raw milk into the pasteurized milk.

Calculation of holding time

The appropriate tube length for the required holding time can be calculated when the hourly capacity and the inner diameter of the holding tube are known. The velocity profile in the holding tube is not uniform. To ensure that all the milk is sufficiently pasteurized, an efficiency factor must be used. This factor (η) depends on the design of the holding tube but is often in the range of 0.8 - 0.9 if the flow is turbulent.

(Tube volume, L) = (Flow, L/h x (Holding time, s) / 3600 x η

(Tube length, dm) = (Volume, L = x 4 / π x (Diameter, dm)^2

To avoid using the second equation, the values for “volumes in stainless steel pipes” can be found in the end of this booklet.

The phosphatase test: for testing the level of heat treatment

In many countries, the phosphatase test is used to determine whether the pasteurization process has been carried out correctly. Phosphatase is an enzyme that is inactivated above certain temperature-time combinations. The temperature-time combinations to inactivate important pathogenic bacteria (e.g. *Tubercle bacilli*) are below the temperature-time combinations for inactivation of phosphatase. Thus, a negative phosphatase test ensures successful inactivation of pathogenic bacteria.

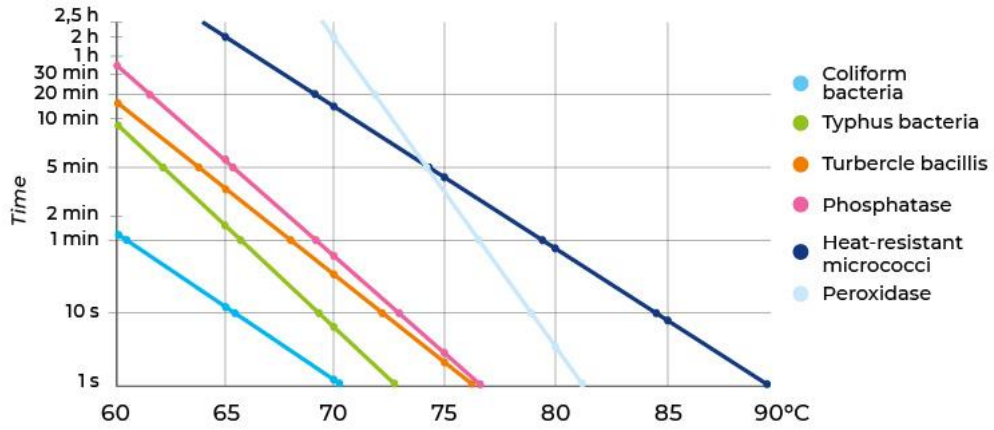

Figure 3. *Time-temperature combinations to inactivate certain enzymes and bacteria.*

CHEESE TYPES

Cheese varieties can be classified in many different ways based on, among other things, the water content, colour, fat content, presence of moulds, region or country of origin. Here we chose to organize cheese types according to process procedures that determine the cheese composition and characteristics.

This results in eight cheese families. The processing of some cheese types is described more in detail in later chapters.

Cheese family	Cheese types	Significant process procedures
Acid-coagulated fresh cheese	Cottage cheese, Quark, Cream cheese, Tvarog	Milk coagulation achieved by acidification (pH 4.6 - 4.8).
Rennet-coagulated fresh cheese	Queso Blanco, Queso Fresco, Halloumi	Milk coagulation through rennet. Little or no culture is used. The pH is determined by the amount of culture. If no culture is used, the pH remains in the range of 6.5 - 6.7.
Heat-acid coagulated cheese	Ricotta, Paneer, some varieties of Latin American white cheese	High heat treatment of milk causes denaturation of the whey proteins. Subsequent acidification of the hot milk coagulates both casein and whey proteins. Final pH is normally pH 5.3 - 5.8.
Soft-ripened cheese	Feta, Camembert, Brie, Blue cheese	Coagulation is primarily by rennet, but acidification has considerable influence. Cutting is delayed and done with large knifes.
Semi-hard washed cheese	Gouda, Edam, Colby, Brick, Montasio, Oka, Muenster, Danbo, Havarti	Coagulation by rennet. Lactose content is reduced in curd by replacing some whey with water. This limits the acidification to pH 5.0 - 5.2. The moisture in the cheese is controlled by varying the temperature and time after the wash water is added.
Hard cheese “(Low temp.)”	Cheddar, Monterey Jack, Pasta Filata types	Milk coagulation by rennet. For Pasta Filata types the curd is worked and stretched in hot water and brine salted. Cheddar types are salted before hooping and pressing.
Hard cheese “(high temp.)”	Romano, Parmesan, Swiss	Milk coagulation by rennet. Little acid development before draining. Moisture content is controlled by temperature during renneting and cooking temperature of curd.
Liquid-filled cheese	Cast white cheese, Cast Feta	Renneting of concentrated acidified milk. The concentrate has the same dry matter as the final cheese.

Table 6. *Cheese types of different cheese families.*

The total solids (TS) content of cheese types varies between 70% (e.g. Parmesan) and 21% (e.g. cottage cheese). The fat content of the cheese is varied by standardization of the cheese milk. This makes it possible to also produce low-fat types of cheeses. The fat content is often given as a percentage of the cheese TS. A fat content of 50% of TS is written as 50+, 45% as 45+, etc. The designation "full-cream cheese" is used for cheese 50+.

Cheese family	Cheese type	Moisture	Protein	Total Fat	Fat in DM	Salt	pH
Acid- coagulated fresh cheese	Cottage	80	17	0.4	2	0.6	5.0
	Quark	72	18	8	28	1.0	4.5
	Tvarog	74	17	5	19	nil	4.5
Rennet-coagulated fresh cheese	Queso blanco	52	23	20	42	2.5	5.8
Heat-acid coagulated cheese	Queso blanco	55	19	20	44	3.0	5.4
	Ricotta	92	11	12	45	<5	5.9
	Paneer	54	24	23	50	1.5	5.8
Soft-ripened cheese	Camembert	51	19	24	50	2.1	6.9
	Feta	55	14	21	47	3.5	4.4
	Blue	42	21	29	50	2.5	6.5
Semi-hard washed cheese	Colby	40	25	31	52	0.6	5.3
	Gouda	41	25	27	46	0.8	5.8
	Edam	41	25	27	47	1.0	5.7
	Havarti	43	24	26	47	2.2	5.9
	Munster	42	23	30	51	1.8	6.2
Hard cheese "(Low temp.)"	Cheddar	37	25	33	52	1.8	5.5
	Mozzarella	54	19	22	47	1.0	5.3
Hard cheese "(High temp.)"	Parmesan	29	36	26	36	3.0	5.4
	Swiss	37	28	27	44	1.2	5.6
Liquid-filled cheese	Cast-white	57	16	17	40	4.2	4.6

Table 7. *Typical composition (weight %) of some common cheese types.*

CHEESE ADDITIVES

Cheese additives are already added to the cheese milk before the rennet coagulation of the milk in the cheese vat. The use of additives can serve various purposes, and not all additives are allowed according to all food legislation.

Calcium chloride

Calcium is naturally present in milk and is crucial to give the coagulum a proper texture. By adding additional calcium, through addition of calcium chloride to the cheese milk (approximately 0.02%), the coagulation process is improved, and the amount of required rennet is reduced. Pasteurization changes the state of calcium in milk. Thus, addition of calcium chloride is especially beneficial if the cheese milk is coagulated directly after pasteurization.

Nitrates

Sodium nitrate or potassium nitrate can be added at levels of circa 0.02% to Edam, Gouda and Swiss cheese to prevent gas production from Clostridia bacteria that grows during ripening. Nitrates do not prevent Clostridia from growing but can prevent gas production. The addition of nitrates can be avoided by opting for the processes of Bactocatch or Bactofugation, both of which reduce the number of Clostridia in milk.

Colouring agents

Cheese colours are added to standardize seasonal changes in colour or give additional colour to some cheeses such as Cheddar and Cheshire. Traditionally, annatto cheese colour has been used for this purpose. Annatto is a carotenoid similar to vitamin A in structure, but it has no vitamin A activity. Annatto colour is red to yellow in pigment, but usually appears as orange at pH > 6. At lower pH, annatto gives a red tone, which mostly appears as pink in the cheese. At pH < 4.8 the pink fades and becomes nearly white. Annatto is bleached by light.

Alternatives to annatto are Beta-carotene, which is often too yellow, Apo-8-carotenal, which has the advantage of not getting lost in the whey, and paprika.

De-colourants

Certain de-colourants are allowed by some legislation. Goat's milk and sheep's milk naturally do not contain carotenes and appear flat white in colour. Cow's milk may be whitened to mimic goat's or sheep's milk by adding titanium dioxide or chlorophyll. Titanium dioxide is a white pigment. Chlorophyll masks the natural yellow colour, but excessive addition makes the cheese green.

Ripening enzymes

There are many products available to accelerate cheese ripening or to develop a broader flavour profile.

Lipases, also lipolytic enzymes, are added to cow's milk to produce cheese such as Feta, which is traditionally made from goat's or sheep's milk. Sheep's milk and (especially) goat's milk contain more natural lipase than cow's milk.

Different cocktails of enzymes from various sources can be added to the milk to accelerate ripening of aged cheese such as Cheddar or Gouda.

CHEESE STARTER CULTURES

The starter culture is added to the cheese milk some time before the rennet enzyme is added to induce coagulation.

Types of starter cultures

The type of starter culture used in cheesemaking influences the end product. The starter culture can contain one type of bacteria (i.e. a single-strain culture) or a mixture of different types of bacteria (i.e. a mixed-strain culture).

The types of bacteria can be divided in two main groups according to their preferred temperature of developing:

- Mesophilic bacteria with an optimum temperature between 77° and 104°F (25° and 40°C).
- Thermophilic bacteria, which develop at up to 122°F/50°C.

Mixed-strain cultures often consist of either a cocktail of mesophilic bacteria or thermophilic bacteria, or sometimes a combination of both. Gouda, Manchego, Tilsiter, Cheddar and American varieties are generally based on mesophilic cultures, and Emmental and Gruyère generally on thermophilic cultures.

Most starter cultures are mixed strain, but single-strain cultures are sometimes used in production of Cheddar and related types of cheese. Two common types of mixed-strain cultures are described below.

In the broadest terms, starter cultures have two purposes in cheesemaking: (i) to develop acidity through production of lactic acid; and (ii) to promote ripening of the cheese. Lactic acid bacteria (LAB) cultures contribute to both of these functions, while numerous special or secondary cultures are added to help with the second function.

Many cultures do not only produce lactic acid, but also have the ability to form carbon dioxide and aroma components. Carbon dioxide is essential for creating the holes in round-eyed cheeses and supports the openness of granular types of cheese. The mesophilic cultures for Cheddar cheese do not produce carbon dioxide.

Mesophilic culture	
Bacteria	**Comments**
Lactococcus lactis ssp. cremoris *Lactococcus lactis ssp. lactis*	As a mixed blend, these two form the most common mesophilic and homofermentative (no gas production) culture. Used for many low-temperature varieties (e.g. fresh cheese, Cheddar, American varieties, etc.)
Lactococcus lactis ssp. lactis biovar. diacetylactis *Leuconostoc mesenteroides ssp. cremoris*	These two species are most commonly used in culture blends that need to produce carbon dioxide. The cultures also add to the flavour profile of the cheeses during ripening.
Thermophilic culture	
Bacteria	**Comments**
Streptococcus salivarius ssp. thermophilus *Lactobacillus helveticus*	Commonly used for high-temperature varieties (Swiss and Italian cheeses). L. helveticus, used to reduce browning in Mozzarella, and to promote proteolysis in Cheddar

Table 8. *Two common cheese cultures, with different species of lactic acid bacteria.*

Starter systems

These bacteria cultures can be produced in different ways and be in the form of a bulk starter or a direct vat starter. The different types of bulk-starter systems can be (i) conventional, (ii) external pH control, and (iii) internal pH control.

Bulk starter systems

A conventional starter is usually made with skim milk at 10% total solids. The medium is heated to 195°F/90°C for 45 minutes to kill any pathogens and bacteriophage. The starter medium is cooled to approximately 78 - 80°F/25 - 27°C for mesophilic cultures and 106 - 108°F/41 - 42°C for thermophilic cultures. The bacteria culture to set the starter vat has been kept frozen in an ultra-cold freezer (-40°F/-40°C) before it is thawed. The starter culture is added to the starter vat and agitated. The starter is allowed to grow to a desired pH. Once the desired pH is reached, the tank is agitated or “broken” and cooled to 40°F/4.5°C. The fermentation requires 12 - 14 hours and the starter culture is added to the cheese vat.

The method of external pH control was developed to produce cultures with maximum acid-production rates while maintaining the optimum pH level for acid production rate (activity) in the cheese vat. These cultures are mainly made for the production of enzymes.

These enzymes are responsible for all kind of flavour developments during ripening. The enzymes are released when the cells are in Lysis state.

The media for pH control systems has a total solids level of 5 - 9% solids. The media is pasteurized before being cooled to the proper inoculation temperature. After the starter is cooled to set temperature, the culture is added and grown for approximately 8 hours. When the pH drops to 5.8, a neutralizer – usually aqua-ammonia – is added until the pH reaches 6.0. This process continues for about 5 - 7 hours or until the pH no longer drops for at least 45 minutes.

In internal pH control systems, magnesium and phosphate buffers are used in the starter medium to control the pH instead of adding a neutralizer. As the pH drops, buffer salts neutralize the acid to maintain the optimum pH for bacterial growth. The internally buffered system can be used for all types of cheeses.

The process time is approximately 12 - 18 hours until a pH of 5.0 - 5.4.

Direct vat starter (DVS)

Another method of achieving the desired pH in cheese varieties is to use a direct vat starter (DVS). For DVS, bacteria have been concentrated, frozen, packaged, and shipped to the cheesemaker. The starter culture is then taken from the freezer and added directly to the cheese vat.

Selecting starter types

Different starter cultures and starter systems are used in cheese production. For example, often a bulk starter system is used in combination with a DVS, which is added directly to the cheese vat. However, DVS is often more expensive than bulk starters. In emergencies, bulk starter can also be replaced by a DVS.

Additionally, when phage problems occur, a simple method of improving the situation is to add some DVS.

Starter problems

Some general problems that occur with starter cultures are inconsistent parameters that affect how the culture grows. For example, if the cooling comes on too soon while the culture is growing in the starter vat, the starter will not have enough cells to produce the amount of acid to achieve the proper specifications. If the culture is stored in a freezer that fluctuates in temperature, the water crystals change in size and crush the bacteria cells. In general, close observation of critical control points is essential in producing good starter and excellent products.

CHEESE PROCESSING

General processing steps

The feature common to all cheesemaking is that the fluid milk coagulates and forms a solid gel (i.e. coagulum) after acidification and/or addition of rennet enzyme. It is the casein proteins of the milk that react due to acidification and rennet addition, creating a ridged network within the coagulum. Fat globules and water get entrapped in the ridged network of casein proteins.

When the coagulum is cut into slabs or cubes, the pieces of coagulum will contract, which in turn, causes whey to expel, a process known as syneresis. The whey contains whey proteins, lactose, minerals, water and a minor amount of fat. Thus, due to syneresis the originally homogenous milk can be separated into curd grains (cheese) and whey.

→ Cheese milk →		
	10 - 15% of total milk	→ **Cheese**
	89 - 94% of fat	
	74 - 77% of proteins	
	85 - 90% of total milk	→ **Whey**
	6 - 11% of fat	
	23 - 26% of proteins	

Table 9. *Transfer of milk and milk components to cheese and whey during curd making.*

Although curd making is an important part of cheesemaking, other processing steps (and their parameters) also heavily affect the quality of both cheese and whey. The sequence and purpose of common processing steps for hard and semi-hard cheese are summarized on the following page.

Processing step	Description and purpose(s)
Thermization, pasteurization, Bactofugation	Heat-treatment to condition milk or to inactivate pathogenic bacteria. Bactofugation removes bacteria.
Separation, standardization	Separation of cream from milk, and then standardization of fat content.
Ripening of milk	Addition of starter culture to ensure culture activity and acid production before rennet is added. Some acidity aids renneting.
Setting milk	Two alternatives that can be combined: - Enzymatic: rennet, which contains the enzyme chymonsin, is added to induce coagulation of the cheese milk. - Acidic: by adding culture or an acid, the pH is lowered enough to induce coagulation of the cheese milk.
Cutting the curd	Cutting of coagulum into curd grains induces whey to be expelled. Proper cutting is extremely important to both quality and yield. Loss of small curd fines to whey should be avoided. Sometimes the coagulum is broken up into pieces instead of cut.
Cooking curd	Is done in production of some cheeses. The combination of heat and the developing acidity (decreasing pH) causes contraction of curd grains and expulsion of whey (including lactose, acid, minerals, salts, and whey proteins). This influences texture and moisture content in final cheese.
Curd handling (including moulding, pre-pressing and Cheddaring)	The curd is fused to form a smooth, plastic mass. Curd can be directly dipped into the forms or pressed under the whey (brine or surface salted varieties), pre-pressed in vat or column under whey before draining (e.g. Gouda and Swiss), or curd is kept warm in the vat or drain table and allowed to ferment to pH 5.2 - 5.4 (e.g. Cheddar, Pasta Filata).
Pressing	Shape the cheese and close up the body. little or no pressures (e.g. soft cheese) up to high pressures (e.g. firm Cheddar cheese) are applied. Mechanical openings may be reduced by vacuum treatment.
Salting	Salting can be done through: [i] addition to curd before pressing, [ii] surface salting of curd block after pressing, [iii] immersion of curd block in salt brine. Influences flavour, moisture content, texture, and decreases starter activity.

Table 10. *General processing steps, and their purpose, during cheesemaking.*

Cheese yield equations

Calculation of cheese yields is important to monitor the efficiency of the cheese process between batches. The actual yield (yA,%) is calculated thus:

(Cheese Weight / Milk Weight) x 100

The actual yield can conceal inefficiency in recovery of fat and protein. To better monitor the recovery of fat and protein, a moisture and salt-adjusted cheese yield (MSACY %) can be calculated. The actual moisture and salt contents of the cheese are then related to reference/target levels of moisture and salt.

MSACY = (AY) [100 – (actual moisture + actual salt)] / [100 – (reference moisture + reference salt)]

The most widely used equation for predicting cheese yield is Van Slyke (VS) formula. The VS formula exists for different cheese types.

VS = [(F x fat in milk) + (casein in milk – A)] x B / [1 – (actual moisture / 100)]

Where F is the coefficient for fat recovery, A is a coefficient for casein loss, and B is a coefficient to account for cheese solids non-fat. For Cheddar, F, A and B are 0.93, 0.1 and 1.09. For low-moisture Mozzarella, F, A and B are 0.86, 0.36 and 1.0.

Typical cheese equipment

Cheese vat

Designed to provide stirring of milk when mixing with rennet, temperature control during milk setting/coagulation, cutting and stirring of curd, partial whey drainage, and cooking and washing of curd. Can be designed with horizontal/vertical single/twin shafts.

Draining belts and conveyors

Multi-level belt designed to provide whey drainage, residence time and Cheddaring for the production of matted curd for Cheddar. The draining conveyor also provides stirring capabilities for the production of granular curd for Pasta Filata cheese types.

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Cheese block forming towers for Cheddar

The milled and salted curd chips are drawn by vacuum to the top of a tower. The curd fuses into a continuous columnar mass. regular blocks of identical size are automatically guillotined, ejected, and bagged. No subsequent pressing is needed.

Cooker-stretcher for Pasta Filata

Used in the manufacture of Pasta Filata type cheeses. Designed to give hard mechanical treatment and cooking of curd grains after milling.

Draining and washing equipment for cottage cheese

Designed as set of enclosed belt conveyors. During the first stage, curd is gently separated from the whey by a permeable belt. During the second stage, cooling water nozzles are used to reduce lactic acid concentration and temperature. For the final stage, curd is squeezed between the belt and a large-diameter roller to separate it from water before sending it to buffering and blending equipment.

Dosing units for cast cheese

Designed for dosing and mixing ultra-filtered cheese milk with rennet and other ingredients. The system mixes the ingredients alternately in two tanks and pumps continuously into the packaging machine.

Loose ingredients dosing units

Used in wide range of cheese making applications, for example citric acid dosing for Paneer or salt dosing for cast Feta. The system consists of an inline mixer installed in a recirculation loop connected to a tank. An ingredient bag is manually emptied into a funnel at the top the mixer. From there, a two-stage pump draws it using the Venturi effect. The homogenous loose ingredient and liquid mixture is then pumped into the tank.

Pre-pressing vats

The whey is drained off in the batch-operated pre-pressing vat and the curd is pre-pressed before being portioned, moulded and finally pressed. The system is used for many European-type hard and semi-hard cheeses (e.g. Danbo, Edam).

Continuous draining and forming systems

Depending on the type of cheese, different types of equipment are used for European-type hard and semi-hard cheeses (e.g. Emmental, Gouda, Havarti). A system consisting of buffer tanks and columns is used before the final pressing. The curd/whey mixture is continuously pumped from the tank to the top of the column. The drainage column can be round or rectangular to suit the cheese to be produced. Due to gravitational force, the curd grains form a cohesive mass. In the bottom of the column, cheese blocks are formed.

Different columns are used for fresh formed cheeses like Tvarog, Panela or Queso Fresco. In those systems, a vacuum is used for draining and no buffer tanks are used. The weight of formed cheese is low – up to one kilogram.

Cheese presses

Designed to perform final pressing of cheese blocks (e.g. Gouda, Emmental, Danbo) in various moulds.

Curd recovery unit

Designed to collect cheese fines from the whey stream after the cheese has been drained.

Curd and whey mixture cooling unit

Designed as tubular heat exchangers, these units are used to continuously adjust the temperature of the curd-and-whey mixture before the forming or draining processes. Used mainly in fresh cheeses production.

Processes for Cheddar cheese types

Cheddar cheese

Depending on quality and type (full fat or low fat), Cheddar cheese contains 35 - 43% moisture and 20 - 60% fat in dry matter. In some countries, a legal limit for fat in dry matter of Cheddar cheese has been set. A common manufacture procedure involves:

- Standardization of milk to protein/fat-ratio of approximately 0.91
- Pasteurization and then cooling down to inoculation temperature (86 - 91°F/30 - 33°C) before adding starter.
- Addition of starter. The ripening time is usually 20 - 60 minutes.
- Addition of colour and/or calcium chloride. Often the colour is diluted in water before addition to the milk.
- Rennet enzyme is added to induce coagulation of the milk. The type of rennet will influence the yield and flavour profile of the cheese further down the process. Renneting time is 30 - 50 minutes.
- Cutting of coagulum using approximately 3/8 in (95 mm) knives. If the size of cutting is smaller, the moisture content of the final cheese will decrease. The cut curd is gently agitated.
- Scalding for approximately 15 minutes after cutting. The temperature is increased to 99 - 106°F/37 - 41°C for 30 minutes (not more than 1°F/5 min) and then held at that temperature until pH is 6.1 (approximately 20 - 75 min). If the acidity increases too quickly, the temperature may be raised slightly (maximum 104°F/40°C) to retard the culture.
- When the curd pH is 6.0 - 6.1 (whey pH 6.2 - 6.3), part of the whey is removed from the vat. The rest of the whey is removed when the curd enters the mechanical Cheddaring equipment. The matted curd is finally milled into small pieces, or chips.
- In the end of the Cheddaring equipment, salt is added to the milled curd. The final salt content of the cheese should be about 1.5 - 2.5%. For 1.7% of salt in the final cheese, the required amount of salt added to the curd is 2.5% of the estimated yield.
- Blocks of curd are formed under vacuum in a blockformer tower. In the lower part of the tower each block is packed in plastic foil.
- The packed cheese is stored for curing. Cold curing (41 - 46°F/5 - 8°C) produces the best cheese but ripening is slow. Warm cured cheese (50 - 61°F/10 - 16°C) develops flavour rapidly but quality control is more difficult.

Process for pizza cheese

Pizza cheese or Pasta Filata cheese types are characterized by a fermentation of the drained curd to pH 4.9 - 5.2 and then followed by a process where the curd is stretched in hot water. This plasticizes the curd and gives the final cheese its characteristic fibrous structure and melting properties. Main steps are:

- Milk is typically standardized to protein/fat-ratio 2.2 and then pasteurized.
- The culture is added, and the milk is pre-ripened for 15 - 45 minutes. Modern cultures contain a strain of *Streptococcus thermophilus,* often in combination with strains of *Lactobacillus delbrueckii* or *Lactobacillus helveticus.*
- Rennet is added and the milk is left to coagulate at 90 - 100°F/32 - 37°C before cutting into curd grains (5 - 15mm).
- The cut curd is gently stirred for 10 - 15 minutes before being drained on a conveyor. pH is 5.3 - 5.2.
- At pH 5.0 - 5.1, hot water (167 - 185°F/75 - 85°C) is added. The curd is then stretched in a cooker (140 - 149°F/60 - 65°C) and formed into cheese blocks.
- The cheese is cooled in chilled water and immersed in brine (10% NaCl) at 60°F/15°C before packing in sealed bags.

Processes for semi-hard cheese

Colby

Colby cheese is characterized by high moisture, open texture, soft body and short curing. The production procedure for Colby is the same as for Cheddar until the correct acidity is attained for dipping. At this time, the final acidity of Colby is adjusted by washing to remove lactose and acid, while in Cheddar, manufacture lactose is removed during Cheddaring. Colby cheese has higher moisture (40-49%) and a softer body than Cheddar, and never attains the sharp character of Cheddar.

- Standardize milk to protein/fat-ratio 0.96, pasteurize and cool to 88°F/31°C before adding starter.
- Starter is added and milk is ripened for approximately 1 h.
- Colour and calcium chloride are added to the milk, then rennet enzyme.
- The formed gel is cut using 3/8" (9.5mm) knives when curd is firm. The curd is gently agitated.
- Cooking is started approximately 15 minutes after cutting. Temperature is slowly increased to 97 - 102°F/36 - 39°C. The temperature is held until whey pH is 6.2 - 6.3.
- When whey pH is 6.2 - 6.3, the whey is drained down to the level of the curd in the cheese vat.

- Water (59°F/15°C) is added until the curd-water mixture is 79°F/26°C. stirring is performed when adding water and for an additional 15 minutes. If the wash water is below (59°F/15°C), less water is added. Colder water produces a cheese with higher moisture content.
- The curd is added to mechanical conveying belts and salted. The salt is left to be dissolved in the curd for 15 minutes before hooping.
- The curd is formed into blocks and vacuum packed by a blockformer tower.
- Curing at 45 - 55°F/7 - 13°C for 1 - 3 months.

Gouda

Gouda cheese originated in the Netherlands and is similar to Edam. Normally, Gouda has a higher fat content than Edam but fat in dry matter can vary from 20 - 60%. Gouda is made in round or block forms and the cheese varies in weight from 600 g to 20 kg. A gas-forming culture is used to induce eye formation.

- Milk is standardized to a protein/fat-ratio of approximately 1.07 and then pasteurized.
- Annatto colour can be added to the milk to standardize colour.
- Starter culture is added. The main part of used cultures is mixed multi-strains originating from *Lactococcus lactis* and *Leuconostic mesenteroides*. In a continuous production, starter is added at the start, filling the vat. Acidification will continue until the cheese enters the brine. Rennet is added when the vat is filled. In Scandinavia, the milk is pre-ripened for 15 – 45 minutes. Acidification continues during coagulation, cutting and stirring.
- Coagulation of the milk is induced by rennet addition. The curd is cut into 0.5 - 1.0 cm cubes. The curd is stirred in whey for up to 30 minutes. Whey pH should be approximately 6.4.
- As much whey as possible (40 – 45%) is discharged before washing water is added. Stirring is continued for approximately 15 minutes.
- The curd is pre-pressed in a tower or a vat.
- The pH after pressing should be 5.3 - 5.5.
- The cheese blocks are immersed in 20% salt brine. The pH should be 5.15 - 5.25.
- The cheeses are coated with wax or plastic, and then incubated at 43 - 68°F/6 - 20°C for 5 - 52 weeks. The pH of Gouda cheese increases during ripening. The pH after 8 weeks should be 5.3 - 5.5.

Process for cottage cheese

Cottage cheese is a soft, un-ripened, white, cooked curd from skim milk. The curd is eventually blended with a dressing that traditionally contains cream and salt but can also have other ingredients.

The fat content of the dressing may be reduced to yield a low-fat product. The curd is manufactured by using short (4 - 5 h), medium (6 - 8 h) or long (8 - 16 h) set times. The set time is dependent upon the rate of inoculation and the temperature of the milk. Important steps are:

- The skim milk is gently pasteurized. Denaturation of whey proteins will harm the texture development of the curd.
- The milk is cooled to setting temperature. For short set 90 - 93°F/32 - 34°C is used and for long set 77 - 82°F/25 - 28°C.
- The culture – and perhaps a small amount of rennet – is added to the milk.
- The coagulated milk is cut in pieces of 10 - 14 mm when pH is 4.7 - 4.8.
- The curd is healed for 10 - 30min and then cooked at 122 - 140°F/ 50 - 60°C for 70 - 130 min. The time is longer at lower temperatures.
- The curd is drained and washed at 36 - 39°F/2 - 4°C before the dressing is added.

Process for Tvarog

Tvarog is a soft, un-ripened fresh white cheese. Depending on the fat content in the final product, three main versions of this product can be found: Tvarog 0%, 5% and 9%. The curd is obtained by acid coagulation – formation of the curd after reaching the isoelectric point of the casein. Coagulation is determined by the addition of starting cultures and usually takes 12 h. The most popular varieties of Tvarog are formed Tvarog (shaped in small blocks) and crumbled Tvarog (packed into bags as loose grains). Important steps are:

- Milk is cooled to the setting temperature of about 82°F/28°C.
- Culture is added to the milk, mixed and left to coagulate for 12 h.
- Curd is ready for treatment after reaching a pH of 4.65 and the correct consistency.
- Curd treatment takes place by breaking the curd and gently heating it.
- In crumbled Tvarog there is an extra phase called hardening, where cold whey is added back to the heated grains to close structure and obtain effect of skin on the surface of grains.
- After treatment, depending on the type of Tvarog, the curd is formed into small blocks or packed into bags in the form of loose grains.

Process for Ricotta

Ricotta is a soft, un-ripened compact cheese with Italian origins. It is made from whey using heat-acid coagulation. Sometimes small amounts of milk are added. Heated whey is treated with a solution of citric acid, which initiates the coagulation of proteins. Because of the small amount of proteins in whey, the yield of standard ricotta is 1 kg of cheese from 30 L of whey. Ricotta has the same consistency as formed Tvarog, is delicate, mild, and has a sweetish flavour. Important steps are:

- Whey preparation – pH correction, pasteurization.
- Heating to the temperature of the process 185 - 198°F/85 - 92°C.
- Citric acid addition and intensive mixing.
- The mixture is left to coagulate for approximately 20 minutes.
- Traditionally, Ricotta is formed in small blocks and eventually minced.

Process for Paneer

Paneer is an un-ripened fresh white cheese with a soft, moist structure, and a delicate and mild taste. The high heated milk is treated with a solution of citric acid, which initiates the coagulation of casein and part of the whey proteins, which creates a mixture of curd lumps in the whey. Traditionally, Paneer is formed in small blocks. Important steps are:

- Preparation of milk for Paneer includes milk standardization for an accurate protein/fat ratio and pasteurization at high temperatures (194 - 203°F/90 - 95°C).
- Before production, milk needs to be heated to the temperature of the process (176 - 185°F/80 - 85°C).
- Citric acid addition and intensive mixing.
- The mixture is left to coagulate for approximately 20 minutes
- The blocks are formed in a forming-draining column or in special moulds.

Processes for liquid filled cheese types

Liquid filled cheese refers to the process when the cheese milk has the same, or nearly the same, total solids as the final cheese. This can be done by using membrane filtration (UF) to separate water from the cheese milk before acidification and rennet coagulation. The drive behind the development of liquid filled cheese has been a more continuous process and an increased yield compared to conventional cheesemaking. The total solids of the cheese milk decrease the amount of expelled whey, also incorporating whey proteins into the cheese. This results in a higher yield, but also some negative effects, such as change in consistency, changes in some functional properties, and slower ripening.

The development of UF based cheesemaking processes has been very successful in certain cases. Liquid filled Feta is one of the most successful examples. It has, however, also been proven that for semi-hard and hard cheese types the high content of whey proteins causes problems which make it difficult and, in some cases, impossible, to produce a cheese of similar quality to traditionally produced cheese.

Brine salting

The salt brine for salting of semi-hard cheeses usually has a sodium-chloride concentration of 16 - 25%. The time for the cheese being immersed in the salt brine depends on the size of the cheese block. Guidelines are: 0.5 kg cheese needs 20h, 3 - 5 kg cheese needs 24 h, and 20 kg cheese needs 5 days or sometimes several weeks.

New brine should be treated with about 0.1% of calcium chloride to prevent sodium being absorbed by the casein proteins on the surface of the cheese block. If sodium is absorbed, the surface of the cheese will bind more water and become soft and slimy. Brine pH should be adjusted to the pH, 4.6 - 5.2 normally of the cheese.

Brine is treated with either MF (microfiltration), kieselguhr filtration or flotation with ozone. Still most important is maintaining hygienic circumstances of brine equipment and environment, preventing yeast and moulds to develop.

MEMBRANE FILTRATION IN CHEESE PROCESSES

Membrane filtration processes have become widely used in cheese processes, as well as in many other dairy processes. The membrane filtration processes are characterized by the capabilities of separating molecules of different sizes and characteristics. The pore sizes of the membranes determine which molecules/particles of the fluid that can be separated. Depending on the pore size of the membranes, distinction is made between four types of membrane filtration techniques: reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF). Due to the difference in pore sizes, the design and operation of the four membrane filtration processes are somewhat different.

Process	Membrane pore size (µm)	Common transmembrane pressure (bar)	Limiting factors for flux of components
RO	10^{-4} - 10^{-3}	30 - 80	Osmotic pressure
NF	10^{-3} - 10^{-2}	20 - 35	Osmotic pressure
UF	10^{-2} - 10^{-1}	1 - 10	Gel formation, Concentration polarization, Retentate viscosity
MF	10^{-1} - 10	< 1	Trans- membrane pressure control, Pore plugging

Table 11. *Operational characteristics and limiting factors for membrane filtration processes.*

Common definitions

There are some very frequently used definitions/expressions that are used in membrane filtration technology:

- Feed: The solution to be concentrated or fractionated.
- Retentate: The concentrate. The liquid retained by the membranes.
- Permeate: The filtrate. The liquid passing through the membrane.
- Flux: The rate of permeate extraction measured in litres per square meter of membrane surface area per hour (l/m^2/h).
- Alternatively, gallons per square foot per day (GFD).
- Concentration factor: The volume reduction achieved by concentration, i.e. the ratio of initial volume of feed to the final volume of retentate.
- Membrane fouling: Deposition, accumulation and binding of feed components on the membrane surface and/or within the membrane pores. This causes an irreversible flux decline during processing.

- Concentration polarization: Due to flux of water/permeate through the membrane the concentration of non-permeating feed components will increase close to the membrane surface.
  This will create a layer that is not bound to the membrane (i.e. compare membrane fouling). This will result in a reversible flux decline.
- Diafiltration: A design to obtain better purification of the retentate. Water is added to the feed during membrane filtration with the purpose of washing out low-molecular feed components (e.g. lactose, minerals) which will pass through the membranes.

Reverse osmosis (RO)

RO is based on very dense membranes, rejecting virtually all soluble substances except water. Thus, RO retains both high- and low- molecular substances, i.e. protein, fat, lactose and dissolved salts. Operating pressure are relatively high in order to overcome the osmotic pressure.

The majority of dairy RO systems are based on spiral-wound elements. The operating pressure is 30 - 80 bar depending on the osmotic pressure of the solution. For applications in the dairy industry, the pressure is usually 30 - 40 bar.

RO is used to concentrate liquids with low solid levels and can replace evaporation up to a point where the osmotic pressure becomes a limitation. The energy costs are much lower for RO since the water does not need to be evaporated and condensed. However, the costs for replacing old membranes must also be considered.

Nanofiltration (NF)

NF is basically a special version of RO, where the membrane structure is more open, allowing mainly smaller ions (e.g. sodium, chloride) to permeate through the membrane. Since the low molecular weight salts pass through the membrane, the osmotic pressure difference across the membrane is reduced, which requires a lower operating pressure. Spiral-wound elements are normally used for NF processes.

Ultrafiltration (UF)

In UF, the membrane is very open in structure and typically allows salts, sugars, organic acids and smaller peptides to pass through the membrane. The osmotic pressure of such high molecular weight compounds is quite low, and consequently, the process is performed at lower pressures than RO and NF; usually in the range of 1 - 10 bar.

UF is a combined separation and concentration process. The limiting factor in reaching high flux rates and well-defined separation is mainly related to the formation of gels on the membrane surface. Operation with high velocities across the membrane surface minimizes this effect.

UF processes are normally based on spiral-wound elements. The flow channels of spiral-wound elements are narrow. If the solids content of the fluid/retentate is high (i.e. high viscosity), elements with wider spacers can be used.

For very dry solids contents, the membrane elements have to be in plate-and-frame modules.

Fluid	Total solids in retentate (%)
Whey (WPC 35 - 80)	35
Skim milk (pH 6.7)	39
Skim milk (pH 4.5)	22
Whole milk (pH 6.7)	52

Table 12. *Indicative values of total solids (TS) contents for different dairy fluids that are obtainable by means of UF plate-and-frame module.*

Microfiltration (MF)

MF is based on a membrane with a more open structure than UF, allowing most dissolved substances to pass through, while non-dissolved particles, bacteria and fat globules are rejected and remain in the retentate.

Thus, the pore sizes are typically in the range of 0.1 - 10 µm. There are also MF membranes with smaller pore sizes (0.01 µm), which then can facilitate separation between whey proteins (0.001 - 0.003 µm) and casein micelles (0.01 - 0.3 µm).

The key to control the MF process is to keep the trans-membrane pressure as low (1 bar or less) and as uniform as possible. This and high fluid velocities across the membrane surface will prevent formation of a gel layer on the membrane surface during MF.

Ceramic membrane elements have been the most suitable alternative for MF plants, but spiral-wound elements are less expensive and are being used more and more.

Applications of membrane filtration

Membrane filtration processes are widely used to concentrate fluids and to separate different components.

Process	Application
RO	Used primarily for the concentration of whey, either for the purpose of reducing transport costs or for subsequent evaporation and drying.
NF	Desalination of whey, milk or permeate from UF.
UF	Protein standardization of milk and concentration of whey. In combination with diafiltration, removal of lactose and soluble minerals can be increased.
MF	Depending on the membrane pore sizes, MF can be differently applied. Protein standardization and separation of whey proteins from milk are becoming more common. Removal of bacteria and spores from cheese milk and cheese brine has been used for a long time in certain geographical areas.

Table 13. *Overview of membrane filtration applications.*

Protein standardization of cheese milk

The centrifugal separator makes it possible to separate fat from milk. By adding a calculated quantity of milk fat back to skim milk, it is possible to standardize the fat content of milk.

By means of UF, whole milk or skim milk can be standardized with regards to protein content. The milk retentate is later mixed with permeate to obtain the right protein concentration. This makes it possible to better control the cheese process. Furthermore, an increased protein content in the cheese milk increases the efficiency of the cheese plant.

In some countries, MF (small pores) is applied to standardize the cheese milk with regards to casein content instead of total protein content. It is actually the casein content, not the total protein content, which determines the cheesemaking properties of the milk. In this way, the curd-making properties can be even better controlled. Furthermore, it will achieve a high-quality whey stream. The whey stream will be free from fat, casein, bacteria, rennet and spores. Thus, the resulting whey is a high-quality raw material for producing whey-protein products.

Bacteria and spore removal in cheese milk

Traditionally, the natural content of anaerobic spores like Clostridia, which survive a normal pasteurization, has been controlled by addition of nitrate and other additives to the cheese milk. The nitrate will, as it is broken down, prevent the anaerobic spore from developing and producing gas, which would seriously destroy or damage the product.

As a result of consumer demands for natural products without addition of preservatives, many markets now reject cheese that has been produced with nitrate.

Centrifugal separation, heat treatment and MF can be used to avoid use of preservatives in cheese. After separation of the cream, the skim milk is treated in the MF plant. The permeate will not contain any spores and the small amount of concentrate containing the spores can then be UHT treated. The cream is also subjected to heat treatment prior to mixing back into the MF permeate.

Concentration of cheese milk

Concentration of cheese milk by UF can be done to different degrees. Depending on the degree of concentration, different configurations of the membranes and different types of cheese equipment (e.g. vats, cutting knives) have to be used.

In pre-concentration, the concentration of the standardized cheese milk becomes a maximum of 2x. This can be used for most cheese types and is followed by the traditional cheesemaking procedure with the normal cheesemaking equipment. If the TS of the cheese milk is doubled, it will increase the utilization of the cheese vats and whey-draining equipment by 100%.

In part-concentration, the cheese milk is concentrated 3 - 5 times and the subsequent cheesemaking procedure is modified. The batch cheesemaking vats are replaced with a coagulation system, which works in a continuous mode. Investment in new equipment and a quality of the cheese that is very different from traditional cheeses have made this process not very successful. Depending on cheese types, this process can increase the yield by as much as 10 - 15%.

If the standardized milk is fully concentrated to the final total solids of the cheese, all whey proteins will be incorporated in the final cheese. To produce viscous milk concentrates, the membranes have to be in a plate-and- frame configuration. This process is used for Cast Camembert, Cast Feta and Cast White cheeses.

Whey processing

Membrane filtration operations play an important role in processing and increasing the value of whey from cheese production. The ability of membrane filtration to both concentrate and separate has resulted in its widespread use in whey processing. UF with diafiltration is especially important to produce whey protein concentrates (WPC) of different qualities. This is described in more detail in chapters ahead.

Cheese brine

The chemical and microbiological quality of brine used for salting of cheese is essential for production of high-quality cheese. The brine may contain unwanted microorganisms including pathogenic bacteria, yeast and moulds. Traditionally, cheese brine has been subjected to different types of treatment, such as heat treatment, kieselguhr filtration, UV radiation, and the addition of preservatives. MF is seen as the ideal process for sanitation of cheese brine because it is fairly simple to operate, does not destroy the balance in the composition of the brine, does not produce any large quantities of waste material, and it is reasonable in terms of maintenance costs.

WHEY AND PERMEATE PRODUCTS

Today the whey solution from cheese production is a valuable raw material for production of whey powder as well as high value-added products like whey protein concentrate (WPC) and whey protein isolate (WPI). The products produced from whey are used in a wide range of food products (e.g. processed meat, sausages, health foods, beverages, confectionery). The quality of the raw whey solution is different depending on the type of manufactured cheese and the control of the cheese process. It is mainly distinguished between sweet whey, from manufacture of hard and semi-hard cheeses, and acid whey, from production of cottage cheese and quark. The sweet whey is less acidic and has the highest quality.

Membrane filtration processes play a major role in the manufacture of whey and permeate products. The membrane filtration processes are used for concentration, demineralization, and separation of lactose before evaporation and spray drying of the whey/permeate into powders.

The first step in whey treatment is separation of fat and small particles of casein (i.e. cheese curd) from the whey by centrifugal separation. The next steps are pasteurization, followed by some sort of concentration, and maybe demineralization.

Products	Proteins (%)	Lactose (%)	Minerals (%)
Sweet whey powder	12 - 15	> 70	< 9
Whey protein concentrate (WPC) powder	35 - 80	5 - 45	3 - 8
Whey protein isolate (WPI) powder	> 90	0.5 - 1.5	< 4
Permeate powder	4 (non-protein nitrogen)	> 85	7 - 9
Lactose powder	< 0.5	> 99	< 0.5

Table 14. *Approximate composition of different whey and permeate powders. Levels of moisture and fat are not given.*

Sweet whey powder

Sweet whey powder is the concentrated and dried product of sweet whey from cheese production. Thus, only the water has been removed. RO can be used to increase the total solids content of the fluid before evaporation and spray drying. With the improved efficiency of evaporators, RO has become less important for concentration before spray drying. However, for concentration of sweet whey up to 15 - 18% TS, RO can still be competitive.

Whey protein concentrate (WPC)

By using UF membrane filtration to concentrate sweet whey, the majority of lactose and minerals will also be separated from the whey proteins. Evaporation and spray drying of this concentrated fluid will result in whey protein concentrates (WPC). This is an effective way of increasing the value of the whey. By applying different degrees of diafiltration, the relative percentage of whey proteins in the final product can be varied. WPC powders can contain 30 - 80% of whey proteins and are labelled WPC30, WPC50, etc.

Whey protein isolate (WPI)

Using extensive diafiltration with UF membranes makes it possible to produce a whey protein isolate (WPI) solution. This solution can then be evaporated, and spray dried to produce a WPI powder with 90% protein of total solids.

Permeate powder

Permeate powders are manufactured from the permeate solution from UF of sweet whey. RO, followed by evaporation and spray drying, are used to produce the powder.

Lactose powder

Lactose powder is produced from the UF permeate of a sweet whey solution. The permeate solution is concentrated to 60 - 70% total solids through RO, followed by evaporation. The concentrated solution is fed to crystallization tanks, where it is seeded with lactose crystals and cooled. The cooling causes super-saturation of lactose and the seeds then initiate crystallization of lactose. Depending on the composition of the permeate, it may be necessary to precipitate calcium phosphate before evaporation by addition of sodium hydroxide (i.e. increased pH). This avoids excessive scaling in the evaporator. After the crystallization process has been completed, the lactose crystals are separated from the remaining liquid (i.e. mother liquor) by means of a centrifugal separation. The crystals are further washed and then transferred to a stationary fluid bed lactose dryer.

CLEANING AND SANITIZING

Good cleaning and sanitation routines provide safety and quality of the cheese and whey products. Consumer safety is assured, while higher and more consistent quality facilitates improved sales and profits.

Active cultures and development of acidity in cheese does not offer adequate protection against pathogenic organisms. It is true that well-made products of some cheese types normally offer significant hurdles to most pathogens, however, several pathogens are known to survive and may even grow under the conditions of cheese manufacturing and ripening. Cheeses with minimal acid development (e.g. Queso Blanco) and cheeses which undergo increased pH during curing (e.g. Brie, Camembert) are especially susceptible to the growth of pathogens. Thus, good hygiene and sanitation are of high importance in the cheese plant, and some very basic routines can be applied.

Location	Guiding routines
Culture room	Separate from milk and cheese processing plant. Positive air pressure. Clean at all times. Restricted access
Drains	Installed water traps. Designed for volumes of whey and wash water during peak periods.
Surfaces	All surfaces clean and sanitizable. All food contact surfaces in stainless steel (exceptions are curing boards and surfaces for cheese ripening).
Personnel	Clean clothes. High personal hygiene (especially hands). Staphylococcus aureus and faecal coliforms often originate from humans.
Plant environment	Ideally have positive air pressure. Raw milk reception separated from rest of plant. Regularly check coliform counts of equipment and employees.

Table 15. *Some basic routines to increase hygiene and food safety.*

Cleaning systems and procedures

Cleaning system and procedure of choice depends on:

- Nature of the soil (fat, protein, milk salts/stone).
- Water quality (hardness) and availability.
- Surface to be cleaned (rough or smooth).
- Method of application (manual or CIP).
- Environmental concerns and legislation.

Heat-treatment can be used to kill microorganisms but should not be used before food soils have been removed. The soils can undergo reactions and result in products that make cleaning more difficult.

Food soil	Fluid for solubility	Ease to remove	Heat-induced reactions
Lactose	Water	Easy	Caramelization
Fats	Alkali	Difficult	Polymerization
Proteins	Alkali	Very difficult	Denaturation
Salts	Water/Acid	Easy to difficult	

Table 16. Properties of food soils.

Stainless-steel surfaces can appear smooth to the human eye. From the perspective of proteins and other molecules, a stainless-steel surface is a world of mountains and valleys, which give possibility for good adsorption. To clean a stainless-steel surface, cleaners must be given time to do their work.

Protein residues on surfaces (e.g. in cheese vat) can be detected with fluorescent light. If the surface reflects a bluish/purple light, there is a residual protein film.

Cleaning procedures for dairy equipment are based on a number of steps. Differences between procedures do exist with regard to times, temperatures and concentration of chemicals.

Step	Fluid / medium	Purpose
Pre-rinse	Water	Removes loose soil
Wash	Chlorinated alkaline detergent solution with chelator, (proteases)	Chlorinated alkaline removes fat and protein, detergent provides wettability, and chelator softens water and removes milk stone.
Rinse	Water	Removes loose soil after wash.
Acid rinse	Nitric, phosphoric solution	Complete removal of milk stone and water hardness
Rinse	Water	Rinse with clean water.
Sanitizing	Thermal and chemical sanitizing	Reduce microbial contamination to a safe level.

Table 17. Main steps for cleaning.

The exact concentrations of cleaning solution and acid during washing and acid rinse, respectively, are given by the manufacturer. Concentrations are dependent on the water quality (e.g. hardness and purity).

Sanitizing

Sanitizing refers to the reduction of microorganisms to levels considered to be safe from a public health point of view. This is different from sterilization (destruction of all living organisms) and disinfection (destruction of all vegetative cells, not spores).

Thermal sanitizing

Thermal sanitizing is most effectively and economically done with hot water. It is relatively inexpensive and penetrates into cracks and crevices. However, it is also a slow process which requires come-up and cool- down time. The time required is determined by the temperature of the water. Legal limits and recommendations for hot-water sanitizing are:

- Minimum 170°F/77°C for 5 minutes. Grade "A" Pasteurized Milk ordinance (2007 revision) of the Food and Drug Administration.
- Minimum 185°F/85°C for 15 minutes. Recommendation of the international Dairy Federation.

Chemical sanitizing

The effectiveness of chemical sanitizing is influenced by the surface characteristics of the equipment. Surfaces which contain biofilms cannot be effectively sanitized. Generally, the longer a chemical sanitizer is in contact with the equipment surface, the more effective the sanitization effect. Temperature is also positively related to microbial kill by a chemical sanitizer. Too high temperatures (> 130°F/55°C) should be avoided because of the corrosive nature of most chemical sanitizers. Furthermore, the activity of a sanitizer generally increases with increased concentration. However, concentrations above recommendations do not sanitize better, but can corrode equipment.

There are two main types of chemical sanitizer:

- No-rinse food contact surface sanitizer
- Non-food contact surface sanitizer

No-rinse food contact surface sanitizers approved by The Food and Drug Administration (FDA) are found in the Code of Federal regulations (21 CFR 178.1010).

The chemical sanitizer can be applied as a spray, foam, or as a circulating fluid. If the time between sanitizing and start-up of the food process exceeds four hours, it is recommended to perform re-sanitizing.

TECHNICAL INFORMATION

Velocity in stainless steel pipes

The velocity in stainless steel pipes should not exceed the values (in m/sec or ft/sec) stated below:

	Suction lines				Pressure lines			
Product	25 mm	1"	101.6 mm	4"	25 mm	1"	101.6 mm	4"
Milk	1.5	5	2	6.6	2	6.6	2.5	8.2
Cream	1.5	5	1.5	5	2	6.6	2	6.6
Water	3	9.8	3	9.8	3	9.8	3.5	11.5

Volume in stainless steel pipes

Outside diameter		Inside diameter		Required flow/CIP		Volume	
Inches	mm	Inches	mm	USG/min	Litre/sec	USG/ft	Litre/m
1	25	0.87	22.1	9	0.5678	0.0309	0.3838
1.5	38	1.37	34.8	23	1.4511	0.0766	0.9513
2	51	1.87	47.5	43	2.7129	0.1427	1.7722
2.5	63.5	2.37	60.2	69	4.3532	0.2292	2.8465
3	76	2.87	72.9	101	6.3721	0.336	4.1729
4	101.6	3.87	98.3	183	11.5455	0.611	7.5882

Tables showing conversion factors between SI units and other common unit systems.

Example showing use of pressure/stress table:

1450 psi converted to bar?

Find factor for bar, line psi = 16.9 x 10-2 x 1450 ~ 100 bar

Length

SI-unit	Other units			
m	in (inch)	ft (foot)	yd (yard)	mile
1	39.4	3.28	1.09	$0.621x10^{-3}$
$2.54x10^{-2}$	1	$8.33x10^{-2}$	$2.77x10^{-2}$	$15.8x10^{-6}$
0.305	12	1	0.333	$0.189x10^{-3}$
0.914	36	3	1	$0.568x10^{-3}$
$1.161x10^{3}$	$63.4x10^{3}$	$5.28x10^{3}$	$1.76x10^{3}$	1

Area

SI-unit	Other units		
m^2	in^2 (sq. inch)	ft^2 (sq. foot)	yd^2 (sq. yard)
1	$1.55x10^3$	10.8	1.20
$0.645x10^{-3}$	1	$6.94x10^{-3}$	$0.772x10^{-3}$
$9.29x10^{-2}$	144	1	0.111
0.836	$1.30x10^3$	9	1

Volume

SI-unit	Other units				
m^3	in^3 (cu. inch)	ft^3 (cu. foot)	yd^3 (cu. yard)	Gallon (UK)	Gallon (US)
1	$61 x 10^3$	35.3	1.31	220	264
$16.4x10^{-6}$	1	$0.579x10^{-3}$	$0.214x10^{-6}$	$3.60x10^{-3}$	$4.33x10^{-3}$
$2.83x10^{-2}$	$1.73x10^3$	1	$3.70x10^{-2}$	6.23	7.48
0.765	$46.7x10^3$	27	1	168	202
$4.55x10^{-3}$	277	0.161	$5.95x10^{-3}$	1	1.20
$3.79x10^{-3}$	231	0.134	$4.95x10^{-3}$	0.833	1

Velocity

SI-unit	Other units		
m/s	km/h	ft/s	Mile/h
1	3.6	3.28	2.24
0.278	1	0.911	0.621
0.305	1.10	1	0.682
0.447	1.61	1.47	1

Density (mass/volume)

SI-unit	Other units		
kg/m^3	g/cm^3 g/mL	lb/in^3	lb/ft^3
1	10^{-3}	$36.1x10^{-6}$	$6.24x10^{-2}$
10^3	1	$3.61x10^{-2}$	62.4
$27.7x10^3$	27.7	1	$1.73x10^3$
16.0	$1.60x10^{-2}$	$5.79x10^{-3}$	1

Mass

SI-unit	Other units	
kg	Metric tech. unit of mass	lb (pound)
1	0.102	2.21
9.81	1	21.7
1.454	4.63×10^{-2}	1

Force, weight

SI-unit	Other units	
N	kp	lbf (pound force)
1	0.102	0.225
9.81	1	2.21
4.45	0.454	1

Moment of force

SI-unit	Other units	
Nm	kpm	lbf x ft
1	0.102	0.738
9.81	1	7.23
1.36	0.138	1

Pressure, stress

SI-unit	Other units				
N/m^2 Pa (pascal)	bar	kp/cm^2, at (tech. atmosph.)	mm H_2O	mmHg torr	lbf/in^2 p.s.i.
1	10^{-5}	10.2×10^{-6}	0.10^2	7.50×10^{-3}	0.145×10^{-3}
10^5	1	1.02	10.2×10^3	750	14.5
98.1×10^3	0.981	1	10×10^3	736	14.2
9.81	98.1×10^{-6}	0.1×10^{-3}	1	7.36×10^{-2}	1.42×10^{-3}
133	1.33×10^{-3}	1.36×10^{-3}	13.6	1	1.93×10^{-2}
6.90×10^3	6.90×10^{-2}	7.03×10^{-2}	703	51.7	1

Standard atmosphere (atm), 1atm = 101325 N/m^2

Energy, work, quantity of heat

SI-unit	Other units				
J,Nm, Ws	kWh	kpm	kcal	Btu (Brit. thermal unit)	ft x lbf (foot pound-force)
1	$0.278x10^{-6}$	0.102	$0.239x10^{-3}$	$.948x10^{-3}$	0.738
$3.6x10^{6}$	1	$0.367x10^{6}$	860	$3.41x10^{3}$	$2.66x10^{6}$
9.81	$2.72x10^{-6}$	1	$2.34x10^{-3}$	$929x10^{-3}$	7.23
$4.19x10^{3}$	$1.16x10^{-3}$	427	1	3.97	$3.09x10^{3}$
$1.06x10^{3}$	$0.293x10^{-3}$	108	0.252	1	779
1.36	$0.377x10^{-6}$	0.138	$0.324x10^{-3}$	$1.29x10^{-3}$	1

Power, heat flow rate

SI-unit	Other units				
W, Nm/s, J/s	kpm/s	kcal/h	Btu/h	Hp (Brit. horse power)	hk (metric horse power)
1	0.102	0.860	3.41	$1.34x10^{-3}$	$1.36x10^{-3}$
9.81	1	8.43	33.5	$1.32x10^{-2}$	$1.33x10^{-2}$
1.16	0.119	1	3.97	$1.56x10^{-3}$	$1.58x10^{-3}$
0.293	$2.99x10^{-2}$	0.252	1	$0.393x10^{-3}$	$0.399x10^{-3}$
746	76.0	641	$2.55x10^{3}$	1	1.01
7.36	75	632	$2.51x10^{3}$	0.986	1

Thermometric scales

Celsius and Fahrenheit degrees

˚C = 5/9 (˚F-32˚) ˚F = (˚C x 9/5) + 32˚

˚C	˚F	˚C	˚F	˚F	˚C	˚F	˚C
-10	14	16	60.8	0	-17.7	52	11.1
-9	15.8	17	62.6	2	-16.6	54	12.2
-8	17.6	18	64.4	4	-15.5	56	13.3
-7	19.4	19	66.2	6	-14.3	58	14.4
-6	21.2	20	68	8	-13.2	60	15.6
-5	23	21	69.8	10	-12.1	62	16.7
-4	24.8	22	71.6	12	-11	64	17.8
-3	26.6	23	73.4	14	-9.9	66	18.9
-2	28.4	24	75.2	16	-8.8	68	20
-1	30.2	25	77	18	-7.7	70	21.1
0	32	26	78.8	20	-6.6	72	22.2
1	33.8	27	80.6	22	-5.5	74	23.3
2	35.6	28	82.4	24	-4.3	76	24.4
3	37.4	29	84.2	26	-3.2	78	25.6
4	39.2	30	86	28	-2.1	80	26.7
5	41	31	87.8	30	-1	82	27.8
6	42.8	32	89.6	32	0	84	28.9
7	44.6	33	91.4	34	1.1	86	30
8	46.4	34	93.2	36	2.2	88	31.1
9	48.2	35	95	38	3.3	90	32.2
10	50	36	96.8	40	4.4	92	33.3
11	51.8	37	98.6	42	5.6	94	34.4
12	53.6	38	100.4	44	6.7	96	35.6
13	55.4	39	102.2	46	7.8	98	36.7
14	57.2	40	104	48	8.9	100	37.8
15	59			50	10		

Saturated Steam Table in ˚C (according to Mollier)

Abs press lb/in²	Temp °C	Enthalpy Steam h_g	Abs press lb/in²	Temp °C	Enthalpy steam h_g
0.1	45.45	617.0	2.5	126.79	648.3
0.2	59.67	623.1	3.0	132.88	650.3
0.3	68.68	626.8	3.5	138.19	651.9
0.4	75.42	629.5	4.0	142.92	653.4
0.5	80.86	631.6	4.5	147.20	654.7
0.6	85.45	633.4	5.0	151.00	655.8
0.7	89.45	634.9	5.5	154.72	656.5
0.8	92.99	636.2	6.0	158.08	657.8
0.9	96.18	637.4	6.5	161.21	658.7
1.0	99.09	638.5	7.0	164.17	659.4
1.1	101.76	639.4	7.5	166.97	660.1
1.2	104.25	640.3	8.0	169.61	660.8
1.3	106.56	641.2	8.5	172.13	661.4
1.4	108.74	642.0	9.0	174.53	662.0
1.5	110.79	642.8	9.5	176.83	662.5
1.6	112.73	643.5	10.0	179.04	663.0
1.7	114.57	644.1	12.5	188.92	665.1
1.8	116.33	644.7	15.0	197.36	666.6
1.9	118.01	645.3	17.5	204.76	667.7
2.0	119.62	645.8	20.0	211.38	668.5

Saturated Steam Table in ˚F (according to Mollier)

Abs press lb/in²	Temp °F	Enthalpy Steam h_g	Abs press lb/in²	Temp °F	Enthalpy Steam h_g
0.08865	32.018	1075.5	95	324.13	1186.2
0.25	59.323	1067.4	100	327.82	1187.2
0.5	79.586	1096.3	105	331.37	1188
1	101.74	1105.8	110	334.79	1188.9
3	141.47	1122.6	115	338.08	1189.6
6	170.05	1134.2	120	341.27	1190.4
10	193.21	1143.3	125	344.35	1191.1
14.696	212	1150.5	130	347.33	1191.7
15	213.03	1150.9	135	350.23	1192.4
20	227.96	1156.3	140	353.04	1193
25	240.07	1160.6	145	355.77	1193.5
30	250.34	1164.1	150	358.43	1194.1
35	259.29	1167.1	160	363.55	1195.1
40	267.25	1169.8	170	368.42	1196
45	274.44	1172	180	373.08	1196.9
50	281.02	1174.1	190	377.53	1197.6
55	287.08	1175.9	200	381.8	1198.3
60	292.71	1177.6	210	385.91	1199
65	297.98	1179.1	220	389.88	1199.6
70	302.93	1180.6	230	393.7	1200.1
75	307.61	1181.9	240	397.39	1200.6
80	312.04	1183.1	250	400.97	1201.1
85	316.26	1184.2	260	404.44	1201.5
90	320.38	1185.3	270	407.8	1201.9

Salt in the moisture phase of cheese (S/M)

Per cent salt

%H_2O	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0
40.0	6.00	5.75	5.50	5.25	5.00	4.75	4.50	4.25	4.00	3.75	3.50	3.25	3.00	2.75	2.50
39.0	6.15	5.90	5.64	5.38	5.13	4.87	4.62	4.36	4.10	3.85	3.59	3.33	3.08	2.82	2.56
38.0	6.32	6.05	5.79	5.53	5.26	5.00	4.74	4.47	4.21	3.95	3.68	3.42	3.16	2.89	2.63
37.0	6.49	6.22	5.95	5.68	5.41	5.14	4.863	4.59	4.32	4.05	3.78	3.51	3.24	2.97	2.70
36.0	6.67	6.39	6.11	5.83	556	5.28	5.00	4.72	4.44	4.17	3.89	3.61	3.33	3.06	2.78
35.0	6.86	6.57	6.29	6.00	5.71	5.43	5.14	4.86	4.57	4.29	4.00	3.71	3.43	3.14	2.86
34.0	7.06	6.76	6.47	6.18	5.88	5.59	5.29	5.00	4.71	4.41	4.12	3.82	3.53	3.24	2.94
33.0	7.27	6.97	6.67	6.36	6.06	5.76	5.45	5.15	4.85	4.55	4.24	3.94	3.64	3.33	3.03
32.0	7.50	7.19	6.88	6.56	6.25	5.94	5.63	5.31	5.00	4.69	4.38	4.06	3.75	3.44	3.13
31.0	7.74	7.42	7.10	6.77	6.45	6.13	5.81	5.48	5.16	4.84	4.52	4.19	3.87	3.55	3.23
30.0	8.00	7.67	7.33	7.00	6.67	6.33	6.00	5.67	5.33	5.00	4.67	4.33	4.00	3.67	3.33

Conversion table

1 inch	x	2.5400	= cm
1 foot	x	0.3048	= m
1 yard	x	0.9144	= m
1 mile	x	1609.0000	= m
1 square inch	x	6.4520	= cm^2
1 square foot	x	0.0929	= cm^2
1 square yard	x	0.8360	= cm^2
1 acre	x	4086.8000	= cm^2
1 cubic inch	x	16.3900	= cm^2
1 cubic foot	x	28.3200	= litre
1 pint (liquid UK)	x	0.5680	= litre
1 pint (liquid US)	x	0.4730	= litre
1 UK quart	x	1.1360	= litre
1 US quart	x	0.9460	= litre
1 US gallon	x	3.7850	= litre
1 UK gallon	x	4.5500	= litre
1 ounce	x	28.3500	= g
1 lb	x	0.4540	= kg
1 short ton	x	907.1800	= kg
1 long ton	x	1016.0600	= kg
1 lb per sq. inch	x	0.0700	= kg/cm^2
1 cm	x	0.3940	= inch
1 m	x	3.2810	= foot
1 m	x	1.0936	= yard
1 km	x	0.6213	= mile
1 cm^2	x	0.1550	= square inch
1 m^2	x	10.7640	= square foot
1 m^2	x	1.1970	= square yard
1 hectare	x	2.4711	= acre
1 cm^3	x	0.0610	= cubic inch
1 m^3	x	35.3200	= cubic foot
1 litre	x	1.7600	= pint (liquid UK)
1 litre	x	2.1100	= pint (liquid US)
1 litre	x	0.2640	= US gallon
1 litre	x	0.2200	= UK gallon
1 g	x	15.4320	= grains
1 kg	x	2.2046	= lb
1 tonne	x	1.1023	= short ton
1 tonne	x	0.9842	= long ton
1 kg/cm^2	x	14.2200	= lb per sq. inch

$^\circ C = 5/9\ (^\circ F-32^\circ)$ $^\circ F = 9/5\ (^\circ C+32^\circ)$ 14.22

Decimal equivalent chart

1/64	=	.0156	33/64	=	.5156
1/32	=	.0313	17/32	=	.5312
3/64	=	.0469	35/64	=	.5469
1/16	=	.0625	9/16	=	.5625
5/64	=	.0781	37/64	=	.5781
3/32	=	.0937	19/32	=	.5937
7/64	=	.1094	39/64	=	.6094
1/8	=	.125	5/8	=	.625
9/64	=	.1406	41/64	=	.6406
5/32	=	.1562	21/32	=	.6562
11/64	=	.1719	43/64	=	.6719
3/16	=	.1875	11/16	=	.6875
13/64	=	.2031	45/64	=	.7031
7/32	=	.2187	23/32	=	.7187
15/64	=	.2344	47/64	=	.7344
1/4	=	.25	3/4	=	.75
17/64	=	.2656	49/64	=	.7656
9/32	=	.2812	25/32	=	.7812
19/64	=	.2969	51/64	=	.7969
5/16	=	.3125	13/16	=	.8125
21/64	=	.3281	53/64	=	.8281
11/32	=	.3437	27/32	=	.8437
23/64	=	.3594	55/64	=	.8594
3/8	=	.375	7/8	=	.875
25/64	=	.3906	57/64	=	.8906
13/32	=	.4062	29/32	=	.9062
27/64	=	.4219	59/64	=	.9219
7/16	=	.4375	15/16	=	.9375
29/64	=	.4531	61/64	=	.9531
15/32	=	.4687	31/32	=	.9687
31/64	=	.4844	63/64	=	.9843
1/2	=	.5	1	=	1

CHEESEMAKING GLOSSARY

Acid curd

The custard-like state that milk is brought to when a high level of acidity is created. The acidity is produced by the activity of starter culture bacteria, and it precipitates the milk protein into a solid curd.

Acidity

The amount of acidity (sourness) in the milk. Acidity is an important element in cheesemaking and is produced by cheese starter culture bacteria.

Aging

A step in cheesemaking in which the cheese is stored at a particular temperature and relative humidity for a specified amount of time in order to develop its distinct flavour.

Albuminous protein

Protein in milk which cannot be precipitated out by the addition of rennet. Albuminous protein, or whey protein, remains in the whey and is precipitated by high temperatures to make Ricotta.

Bacteria

Microscopic unicellular organisms found almost everywhere. Lactic acid-producing bacteria are helpful and necessary for the making of quality hard cheeses.

Bacteria linens

A red bacterium which is encouraged to grow on the surfaces of cheeses like Brick or Limburger to produce a sharp flavour.

Bacterial-ripened cheese

A cheese upon which surface-bacterial growth is encouraged to develop in order to produce a distinct flavour. Brick and Limburger are examples of bacterial-ripened cheeses.

Cheese colour

A colouring added to the milk prior to renneting which will impart various shades of yellow to the cheese. Most colouring is a derivative of the annatto tree.

Cheese salt

A coarse flake salt. A non-iodized salt is the most desirable type to use in cheesemaking.

Cheese starter culture

A bacterial culture added to milk as the first step in making many cheeses. The bacteria produce an acid during their life cycle in the milk. There are two categories of starter culture: mesophilic and thermophilic.

Cheese wax

A pliable wax with a low melting point which produces an airtight seal which will not crack. Most hard cheeses are waxed.

Clean break

The condition of the curd when it is ready for cutting. A finger or thermometer inserted into the curd at a 45-degree angle will separate the curd firmly and cleanly if the curd has reached that condition.

Cooking

A step in cheesemaking during which the cut curd is warmed to expel more whey.

Curd

The solid custard-like state of milk achieved by the addition of rennet. The curd contains most of the milk protein and fat.

Cutting the Curd

A step in cheesemaking in which the curd is cut into equal-sized pieces.

Draining

A step in cheesemaking in which the whey is separated from the curd by pouring the pot of curds and whey into a cheesecloth-lined colander.

Drip tray

A tray which is placed under a mould during the pressing of a cheese. The drip tray allows the whey to drain into a sink or container.

Homogenization

A mechanical breaking up of the fat globules in milk so that the cream will no longer rise in the milk.

Lactic acid

Acid created in milk during cheesemaking. Cheese starter culture bacteria consume the milk sugar (lactose) and produce lactic acid as a by-product.

Lactose

The sugar naturally present in milk. Lactose can constitute up to 5 per cent of the total weight of milk.

Milling

A step in cheesemaking during which the curd is broken into smaller pieces before being placed in a cheese press.

Mould-ripened cheese

A cheese with a surface (and/or interior) upon which a mould is encouraged to grow. There are two types of mould which are most common in cheesemaking. They are blue mould for blue cheeses and white mould for Camembert and relatedcheeses.

Moulding

A step in cheesemaking during which the curd is placed in a cheese mould. The cheese mould will help produce the final shape of the cheese and aids in drainage.

Pasteurization

The heating of milk to destroy pathogenic organisms which may be harmful to man.

Pressing

A step in cheesemaking during which the curds are placed in a cheesecloth-lined mould and placed under pressure to remove more whey.

Raw milk

Milk which is taken fresh from the animal and has not been pasteurized.

Rennet

Rennets are enzymes of animal or vegetable origin. Rennet has the ability to coagulate milk. Animal rennet was originally extracted from the fourth stomach of a calf. Rennets are available in liquid and dried form.

Renneting

A step in cheesemaking in which rennet is added to milk in order to induce coagulation.

Ripening

A step in cheesemaking in which the milk is allowed to undergo an increase in acidity due to the activity of cheese starter culture bacteria.

Salting

A step in cheesemaking in which coarse flake salt is added to the curds before moulding or to the surface of the finished cheese.

Whey

The liquid portion of milk which develops after coagulation of the milk protein. Whey contains water, milk sugar, albuminous proteins, and minerals.

White mould

A white mould (*Penicillium candidum*) which is encouraged to grow on a number of soft cheeses in order to develop a pungent flavour. Camembert is perhaps the most famous of these cheeses.

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