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Dairy Technology Handbook

Dairy Technology

HANDBOOK



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FOOD+BEVERAGE

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Basic Dairy

Products and Processes

% w/w	Whole milk	Skimmed milk	Sweet Whey	Acid Whey	Cream 40% fat
Fat	4.15	0.05	0.05	0.05	40
Total Protein	3.3	3.3	0.75	0.75	2.1
Lactose and acids	4.8	4.9	4.7	4.5	3.1
Total ash	0.75	0.75	0.5	0.65	0.5
Total solids	13.0	9.0	6.0	6.0	45.7

Guideline compositions of typical dairy products.

Milk

Density of Milk

The density of milk is equivalent to the weight in kilos of 1 litre of milk at a temperature of 15°C.

The easiest way to determine the density is to use a special type of hydrometer called a lactometer. The upper part of the lactometer is provided with a scale showing the lactometer degree, which, when added as the second and third decimal to 1.000 kg, indicates the density of milk, ie, a lactometer degree of 30 corresponds to a density of 1.030 kg/litre.

The lactometer is lowered into the milk and when it has come to rest, the lactometer degree can be read on the scale at the surface level of the milk.

As milk contains fat and as the density depends on the physical state of the fat, the milk should be healed to 40°C and then cooled to 15°C before the density is determined. If the, determination of the density is not carried out at exactly 15°C, the reading must be converted by means of a correction table.

The density of milk depends upon its composition, and can be calculated as follows:

$$\frac{100}{\frac{\%\ \text{fat}}{0.93} + \frac{\%\ \text{protein}}{1.45} + \frac{\%\ \text{lactose+acid}}{1.53} + \frac{\%\ \text{ash}}{2.80} + \frac{\%\ \text{water}}{1.0}}$$

Density:

1 litre	whole milk	approx.	1.032	kg
-	skimmilk	-	1.035	kg
-	buttermilk	-	1.033	kg
-	skimmed whey 6.5% TS	-	1.025	kg
-	cream with 20% fat	-	1.013	kg
-	cream with 30% fat	-	1.002	kg
-	cream with 40% fat	-	0.993	kg

Yields from Whole Milk etc.

100 kg standardised whole milk yields:

with	4.0 %	fat	approx.	4.75	kg	butter	
-	4.0 %	-	-	13.0	-	whole milk powder	
-	3.0 %	-	-	9.5	-	45% cheese	*)
-	2.5 %	-	-	9.1	-	40% -	*)
-	1.6 %	-	-	8.3	-	30% -	*)
-	1.0 %	-	-	8.0	-	20% -	*)
-	0.45%	-	-	7.4	-	10% -	*)

100 kg skimmilk with 9.5% solids yields:

approx.	9.8	kg	skimmilk powder	
-	6.9	-	skimmilk cheese	*)
-	7.5	-	raw casein	
-	3.5	-	dried casein	

100 kg buttermilk with 9.0% solids yields:

approx.	9.3	kg	buttermilk powder

100 kg unskimmed whey with approx. 7.0% solids yields:

approx.	0.4	kg	whey butter
-	7.2	-	whey cheese

100 kg skimmed whey with approx. 6.5% solids yields:

approx.	6.7	kg	whey powder
-	3,5	-	raw lactose
-	3.0	-	refined lactose
-	8.0	-	lactic acid
-	2.2	-	WPC 35
-	1.2	-	WPC 60
-	0.9	-	WPC 80

*) ripened cheese

Determination of Fat Content in Milk and Cream

Röse-Gottlieb (RG)

The fat globule membranes are destroyed by ammonia and heat, and the phospholipids are dissolved with ethanol. After

heat treatment, the fat is extracted with a mixture of diethyl ether and light petroleum. Then the solvents are removed by evaporation and the fat content is determined by weighing the mass left after evaporation.

Schmid-Bondzynski-Ratzloff (SBR)
This method uses hydrochloric acid instead of ammonia to destroy the fat globule membranes and is used for cheese samples.
The principal difference between RG and SBR is that the free fatty acids are not extracted by the RG method since the analysis is made in alkaline media. The free fatty acids are extracted by the SBR method since the analysis is made in an acidic medium.

Gerber's method
Whole milk is analysed as follows:
Measure into the butyrometer 10 ml sulphuric acid, 11 ml milk (in some countries only 10.8 ml) and 1 ml amyl alcohol, in that order.
Before measuring out the milk, heat to 40°C and mix care- fully. Insert the stopper and shake the mixture while holding the stopper upwards. Then turn the butyrometer upside down two or three times until the acid remaining in the narrow end of the butyrometer is mixed completely with the other constituents.
During the mixing process, the temperature rises to such a degree that centrifugation can take place without further heating. The butyrometer is centrifuged for 5 minutes at 1,200 rpm and the sample is placed in a water bath at 65-70°C before reading. The reading is made at the lowest point of the fat meniscus.

Skimmilk and buttermilk are analysed as follows:
The acid, milk and amyl alcohol are measured out as described above. Immediately after shaking, the sample is cooled to 10-20°C before the sulphuric acid remaining in the narrow end of the butyrometer is mixed in by turning the butyrometer up and down. Before centrifugation, the sample is heated to 65-70°C. The butyrometer is centrifuged for 10-15 minutes at 1,200 rpm and the value read at 65-70°C.
When skimmilk samples are read, the fat will be seen as two small triangles. If these two triangles are just touching each other, the milk contains approx. 0.05 % fat. For buttermilk samples, the reading is taken at the lowest point of the fat meniscus and the figure of 0.05 is then added to give the fat content.

Cream is analysed as follows:
Measure into the butyrometer 10 ml sulphuric acid, 5 ml cream, 5 ml water, and 1 ml alcohol. The water is used for removing the remainder of the cream from the cream pipette into the butyrometer and must have a temperature of 40°C. Insert the stopper and continue as described for whole milk. Before a reading is taken, *the bottom of the fat column must* be set at zero on the butyrometer by turning the rubber stopper to move it up or down.

Milkoscan
The Danish company N. Foss Electric has developed an instrument, the Milkoscan, for rapid and simultaneous, determination of fat, protein, lactose and water.
In this instrument, the sample is diluted and homogenised. Then the mixture passes through a flow cuvette where the different components are measured by their infrared absorption.

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

The value for 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.

Determination of Protein Content in Milk and Cream

Kjeldahl's method
Kjeldahl's method provides for accurate determination of the milk protein content. This method involves the combustion of the protein contained in a specific quantity of milk in sulphuric acid with an admixture of potassium sulphate and copper sulphate. This converts nitrogen from organic compounds into ammonium ions. The addition of sodium hydroxide liberates ammonia, which distils over into a boric acid solution. The amount of ammonia is determined by hydrochloric acid titration. The protein content is found by multiplying the measured nitrogen quantity by 6.38.

The amido black method (Pro-milk)
When milk is mixed with an amido black solution at pH 2.45, the positively charged protein molecules are linked to the negatively-charged amido black molecules in a specific ratio, and the protein is precipitated. When the precipitate of coloured

protein pigment has been removed, the concentration of non-precipitated pigment, which is measured by means of the photometer, is inversely proportional to the milk protein content.
This method has been automated in an instrument, the Promilk, from N. Foss Electric. The instrument filters out the protein pigment by means of special synthetic filters and a photometer displays the protein percentage directly.

Detection of Preservatives and Antibiotics in Milk

The growth of lactic acid bacteria may be inhibited by the presence in the milk of ordinary antiseptics (such as boric acid, borax, benzoic acid, salicylic acid, salicylates, formalin, hydrogen peroxide) or antibiotics (penicillin, aureomycin, etc). In order to find out which of the above mentioned substances is present, it is necessary to test for each of them - which is both costly and time-consuming.
However, tests for rapid determination ¯f antibiotics, especially penicillin, in milk have been developed. One of these is the Dutch Delvotest P.
A special substrate containing *Bacillus colidolactis,* which is highly sensitive to penicillin and to some extent also to other antibiotics, is inoculated with the suspected milk. After 2 1/2 hours, the quantity of acid produced will be sufficient to change the colour in the dissolved pH indicator from red to yellow. This method gives a definite determination of the penicillin concentration down to 0.06 I.U./ml.
Rapid detention of slow-ripening milk can be achieved by a comparison of the acidification process in the suspected sample with that in a sample of mixed milk.
Both samples are heat-treated at 90-95°C for approx. 15 minutes, cooled to approx. 25°C, and mixed with 2% starter.
After 6-8 hours there will be a distinct difference in the titres (or pH) of the two samples if one of them contains antibiotics or other growth-inhibiting substances.

Acidity of Milk

Normally, fresh milk has a slightly acid reaction. The acidity is determined by measuring either the titrated acidity, i.e., the total content of free and bound acids, or by measuring the pH value, which indicates the true acidity (the hydrogen ion concentration).
The titrated acidity of fresh milk is 16-18, and pH is 6.6-6.8.

Titration

Normally, the titrated acidity of milk is indicated by the number of ml of a 0.1 n sodium hydroxide solution required to neutral-

ise 100 ml of milk, using phenolphthalein as an indicator.
By means of a pipette, 25 ml of milk is measured into an Erlenmeyer flask. To this 13 drops of a 5% alcoholic phenolphthalein solution is added, and from a burette 0.1 n sodium hydroxide solution is added, drop by drop, into the flask until the colour of the liquid changes from white to a uniform pale red. Since for practical reasons only 25 ml of milk is used in the analysis, the figure obtained must be multiplied by four.
Consequently, supposing that the quantity of sodium hydroxide solution used was 5 ml, the titratable acidity would be:

$$5 \times 4 = 20$$

The normal titratable acidity of fresh milk is 16-18. If the titratable acidity increases to 30 or more, the casein content will be precipitated when the milk is heated.
When cultured milk or buttermilk is titrated, part of the milk will stick to the inside of the pipette. This residue is washed into the Erlenmeyer flask by milk taken from the flask after neutralisation takes place and the red colour starts to appear. Titration then proceeds as explained above.
The acidity of cream is determined by the same procedure.
When the final result is calculated, the fat content of the cream must be taken into account. Supposing that the latter is 30% and that the quantity of sodium hydroxide solution used was 2.8 ml, the titratable acidity of the cream would be:

$$2.8 \times 4 \times \frac{100}{100-30} = 16$$

The acidity of milk is expressed in various ways in various countries.
Soxhlet Henkel degrees (S.H.) give the number of ml of a 0.25 n NaOH solution necessary to neutralise 100 ml of milk, using phenolphthalein as an indicator.
Thörner degrees of acidity indicate the number of ml of a 0.1 n NAOH solution required to neutralise 100 ml of milk to which two parts of water have been added. Phenolphthalein is used as an indicator.
Dornic degrees of acidity give the number of ml of a 119 n NAOH solution necessary to neutralise 100 ml of milk, using phenolphthalein as an indicator Divided by 100, the figure gives the percentage of lactic acid.
In the various methods of analysis, the milk is diluted to different degrees, and it is therefore only possible to make approximate comparisons of the various degrees of acidity. However,

working only from the amount of NaOH used and the normal acidity figure, the various degrees of acidity can be compared as shown below:

Degrees of acidity	Soxhlet-Henkel	Tömer	Dornic	Approx. % lactic acid
2.5	1	2.5	2.25	0.0225
5.0	2	5.0	4.50	0.0450
7.5	3	7.5	6.75	0.0675
10.0	4	10.0	9.00	0.0900
12.5	5	12.5	11.25	0.1125
15.0	6	15.0	13.50	0.1350
17.5	7	17.5	15.75	0.1575
20.0	8	20.0	18.00	0.1800
22.5	9	22.5	20.25	0.2025
25.0	10	25.0	22.50	0.2250
27.5	11	27.5	24.75	0.2475
30.0	12	30.0	27.00	0.2700

Measurement of pH

The true acidity of a liquid is determined by its content of hydrogen ions.

Acidity is measured in pH value, pH being the symbol used to express the negative logarithm of hydrogen ion concentration. For example, a solution with a hydrogen ion concentration of 1:1,000 or 10-3 has a pH of 3. The neutral point is pH 7.0. Values below 7.0 indicate acid reactions, and values above 7.0 indicate alkaline reactions. A difference in pH value of 1 represents a tenfold difference in acidity, ie, pH 5.5 shows a degree of acidity ten times higher than pH 6.5.

In milk, it is the pH value and not the titratable acidity that controls the processes of coagulation, enzyme activity, bacteria growth, reactions of colour indicators, taste, etc. The pH value is measured by a pH-meter with a combined glass electrode, and the system must always be calibrated properly before use.

The Phosphatase Test

The phosphatase test is used to control the effect of HTST pasteurisation and batch pasteurisation of milk. Milk pasteurised

by one of these methods must be healed in such a way that, when the phosphatase test is applied, a maximum of 0.010 mg free phenol is liberated per ml milk.
However, the heat treatment must not be so effective that the reaction of the milk to Storch's test (peroxidase test) is negative.

The phosphatase test is performed as follows:
Measure 1 ml milk into two test tubes, marked A and B. Transfer test tube B to a 80"C water bath for 5 minutes and then cool. To the milk in test tube A, add 5 ml distilled water saturated with chloroform and 5 ml substrate solution (prepared by dissolving one small "Ewos" phosphatase tablet I in 25 ml of a solution consisting of 9.2 g pure an- hydrous sodium carbonate and 13.6 g sodium bicarbonate in 1 litre distilled water saturated with chloroform).
To test tube B, add 5 ml diluted phenol solution (0.010 mg phenol in 5 ml) and 5 ml substrate solution. Shake both test tubes and leave them in a water bath at 38-40°C for one hour. Then, to both tubes, add exactly six drops of phenol reagent (three "Ewos" phosphatase tablets II in 10 ml 93% alcohol), and shake the tubes vigorously. Leave the two test tubes at room temperature for 15 minutes and compare them. Only if the contents of test tube A appear paler in colour than the contents of test tube B can the milk be considered sufficiently heated.
If the milk fails this test, a sample for control testing should be sent to an authorised research institute, which will carry out the phosphatase test in such a way that colour is extracted after incubation. The colour extinction is a measure of the content of phenol and can be measured in a Pullfricphotometer.

Standardisation of Whole Milk and Cream

In many countries, milk and cream sold for consumption must contain a legally fixed fat percentage, although slight variations are usually allowed.
In Denmark, for example, the fat content of heat-treated whole milk must be 3.5%, in low-fat milk 1.5% and 0.5%, and in skimmilk 0.1%. The various types of cream must have a fat content of 9, 13, 18, or 36%, respectively.
In order to comply with these regulations, it is necessary to standardise the fat content. This can be done in various ways depending on the stage at which standardisation is carried out. Standardisation before or during heat treatment is to be preferred as the danger of subsequent contamination is thereby reduced. Standardisation will normally take place automatically

during the separating and pasteurising process. It may, however, be done manually as a batch process, in which case the table below may be used.

Table for standardisation of Whole Milk:

% fat in whole milk	% fat in standardised milk										
	4.0	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0
4.5	12.7	15.6	18.7	21.9	25.4	30.0	32.8	36.9	41.3	45.9	50.8
4.4	10.1	13.0	16.0	19.2	22.5	26.0	29.9	33.8	38.1	42.6	47.5
4.3	7.6	10.4	13.3	16.4	19.7	23.2	26.9	30.8	34.9	39.3	44.1
4.2	5.1	7.8	10.7	13.7	16.9	20.3	23.9	27.7	31.7	36.1	40.7
4.1	2.5	5.2	8.0	11.0	14.0	17.4	20.9	24.6	28.6	32.8	37.3
4.0		2.6	5.3	8.2	11.3	14.5	17.9	21.5	25.4	29.5	33.9
3.9	0.36		2.7	5.5	8.5	11.6	14.9	18.5	22.2	26.2	30.5
3.8	0.77	0.38		2.7	5.6	8.7	11.9	15.4	19.0	23.0	27.1
3.7	1.15	0.77	0.38		2.8	5.8	9.0	12.3	15.9	19.7	23.7
3.6	1.54	1.15	0.76	0.38		2.9	6.0	9.2	12.7	16.4	20.3
3.5	1.92	1.53	1.15	0.76	0.38		3.0	6.1	9.5	13.1	16.9
3.4	2.31	1.92	1.53	1.14	0,6	0.38		3.1	6.3	9.8	13.9
3.3	2.69	2.30	1.91	1.52	1.14	0.75	0.38		3.1	6.6	10.2
3.2	3.08	2.68	2.29	1.90	1.52	1.13	0.75	0.37		3.3	6.8
3.1	3.46	3.07	2.67	2.28	1.89	1.51	1.13	0.75	0.37		3.4
3.0	3.85	3.45	3.05	2.66	2.27	1.89	1.50	1.12	0.75	0.37	

The figures above the shaded lines indicate the amount in kg of skimmilk to be added per 100 kg whole milk when the fat content is too high.
The figures below the shaded lines indicate the amount in kg of cream with 30% fat to be added per 100 kg whole milk when the fat content is too low.

Batch Standardisation
For batch standardisation the following equations may be used.

Fat content to be reduced:
To reduce the fat content in y kg whole milk, add x kg skimmilk.

$$\text{x kg skimmilk} = \frac{\text{y (\% fat in whole milk - \% fat required)}}{\text{\% fat required - \% fat in skimmilk}}$$

To obtain z kg standardised milk, mix y kg whole milk with x kg skimmilk.

$$\text{y kg whole milk} = \frac{\text{z (\% fat required - \% fat in skimmilk)}}{\text{\% fat in whole milk - \% fat in skimmilk}}$$

x kg skimmilk = z - y

Fat content to be increased:
To increase the fat content in y kg low-fat milk, add x kg cream (or high-fat milk).

$$\text{x kg cream} = \frac{\text{y (\% fat required - \% fat in low-fat milk)}}{\text{\% fat in cream - \% fat required}}$$

To obtain z kg standardised milk, mix y kg low-fat milk with x kg cream (or high-fat milk).

$$\text{y kg low-fat milk} = \frac{\text{z (\% fat in cream - \% fat required}}{\text{\% fat in cream - \% fat in low-fat milk}}$$

x kg cream = z - y

In-line Standardisation
For in-line standardisation the following equations may be used.

Fat content to be reduced:
To obtain z kg standardised milk, use y kg whole milk. Surplus cream x kg.

$$\text{y kg whole milk} = \frac{\text{z (\% fat in surplus cream - \% fat required)}}{\text{\% fat in surplus cream - \% fat in whole milk}}$$

x kg surplus cream = y - z

To obtain x kg surplus cream, use y kg whole milk. Standardised milk z kg.

$$\text{y kg whole milk} = \frac{\text{z (\% fat in cream - \% fat in standardised milk)}}{\text{\% fat in whole milk - \% fat in standardised milk}}$$

z kg standardised milk = y - x

y kg whole milk used will result in z kg standardised milk and x kg surplus cream.

$$\text{z kg stand. milk} = \frac{\text{y (\% fat in surplus cream - \% fat in shole milk)}}{\text{\% fat in surplus cream - \% fat in stand. milk}}$$

x kg surplus cream = y - z

Fat content to be increased:
Standard in-line systems cannot be used for this purpose. The fat content of skimmilk is normally estimated at 0.05%.

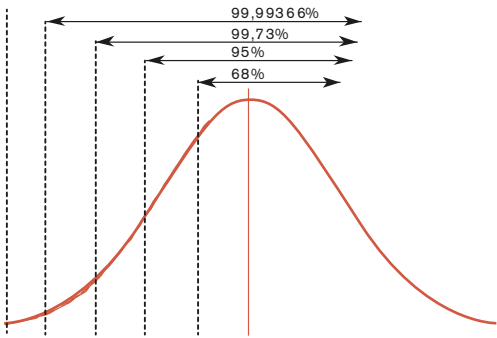
Standard Deviation

The accuracy of an automatic butter fat standardising unit will commonly be expressed in the term Standard Deviation (SD).

By stating a SD figure, it is guarantied that a certain percentage of the fat standardised milk will be kept within the upper and lower limits, which are derived from the standard deviation figure *(cf. the below table).*

Guaranteed Sigma	Percent within the specification	Defects per 1000	Defects per million
1σ	68%	317.40	-
2σ	95%	45.60	-
3σ	99.73%	2.70	2.700
4σ	99.99366%00	0.063	63.4
5σ	99.9999426%0	-	0.574
6σ	99.9999998026%	-	0.001974

It is assumed that the data are distributed normally!



If for instance the SD figures for a fat value range from 1% to 5% are:

SD of the automatic butter fat standardising unit: 0.015%
*) SD of the controlling lab instrument: 0.01%

Then the two SD figures shall be added as follows:

$$\sqrt{(\text{SD of the automatic standardising system})^2 + (\text{SD on the measuring instrument})^2}$$

$$\sqrt{0.015^2 + 0.01^2} = 0.018\%$$

The summarised SD will thus be = 0.018%

Conferring the above table, the accuracy to be obtained will be as follows:

1σ level: 68% of the production time the fat value will lie within ± 0.018%
2σ level: 95% of the production time the fat value will lie within ± 0.036%
3σ level: 99.7% of the production time the fat value will lie within ± 0.054%
4σ level: 99.99366% of the production time the fat value will lie within ± 0.072%

The above accuracy figures can now be used to calculate the fat value set point of the automatic standardising unit.

If a dairy for instance must guarantee minimum 3.4% fat in 99.7% (3σ) of the milk delivered, then the fat value set point of the automatic standardising unit must be 3.4% + 0.054% = **3.454%**

*) There is a degree of accuracy connected with the measuring equipment. The supplier of the measuring instrument expresses this by stating the standard deviation of the measurements to be xxx%.

Calculating the Extent of Random Sampling

How many samples need to be taken in order to prove that the standardising unit will comply with the granted guarantees?

Various methods are available for calculating the extent of a random sampling – this is a simple method.
From the below chart the relation between the Number of Degree of Freedom Required (the number of samples taken) to estimate the standard deviation within P% of Its True Value with Confidence Coefficient γ can be read.

A Confidence Coefficient γ = 95 would normally apply for the dairy and food industry.

Example (above example continued):
Verification of the SD guarantee of 0.018%:
- Number of samples 30 and
- Confidence Coefficient (γ = 95)

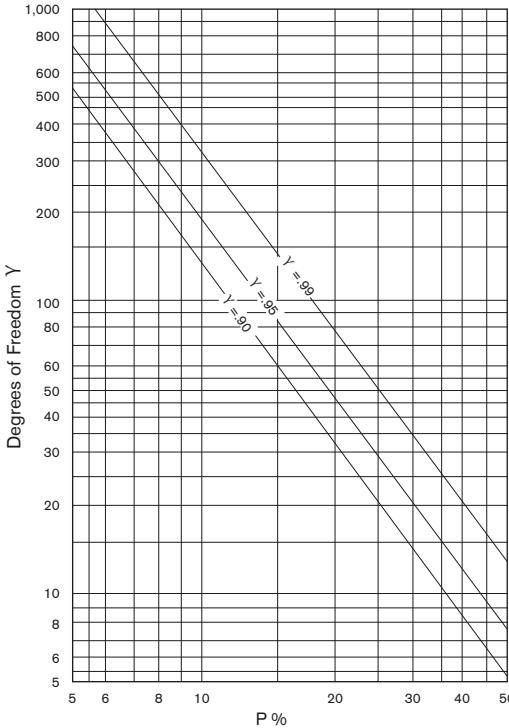
Referring to the below chart, 25% (P%) deviation from Its True Value (0.0018%) must be allowed for.

Due to the analysis uncertainty, the calculated SD of the 30 random samples must thus be better than 0.018% + 25% = 0.023%.

Logically, if the number of samples is increased the deviation (P%) from Its True Value to be allowed for will narrow in. The magnitude hereof is illustrated in the below examples:

Number of samples	P%	Required SD in sample set
30	25%	0.023%
80	15%	0.021%
200	10%	0.020%
N (total)	0%	0.018%

*Chart T *): Number of Degrees of Freedom Required to Estimate the Standard Deviation within P% of Its True Value with Confidence Coefficient γ*



*) Adapted with permission from Greenwood, J. A. and Sandomire, M. M. (1950). "Statistics Manual, Sample Size Required for Estimating the Standard Deviation as a Percent of Its True Value". *Journal of the American Statistical Association*, vol. 45, p. 258. The manner of graphing is adapted with permission from Crow, E. L. Davis, F. A. and Maxfield, M. W. (1955). *NAVORD Report 3369*. NOTS 948, U.S. Naval Ordnance Test Station, China Lake, CA. (Reprinted by Dover Publications, New York, 1960).

Generel Milk Processing

Pasteurisation

Pasteurisation is a heat treatment applied to milk in order to avoid public health hazards arising from pathogenic microorganisms associated with milk. The process also increases the shelf life of the product. Pasteurisation is intended to create only minimal chemical, physical and organoleptic changes in products to be kept in cold storage.

Pasteurisation temperature and time

The temperature/time combinations stated below are similar in effect and all have the minimum bactericidal effect required for pasteurisation.

Pasteurised milk and skimmilk	63°C/30 min. 72°C/15 sec.
Pasteurised cream (10% fat):	75°C/15 sec.
- - (35% fat):	80°C/15 sec.
Pasteurised, concentrated milk, ice cream mix, sweetened products, etc.	80°C/25 sec.

In each case the product is subsequently cooled to 10°C or less - preferably to 4°C.
In some countries, local legislation specifies minimum temperature/time combinations.

In many countries, the phosphatase test is used to deter- mine whether the pasteurisation process has been carried out correctly. A negative phosphatase test is considered to be equivalent to less than 2.2 microgrammes of phenol liberated by 1 ml of sample or less than 10 microgrammes para-nitrophenol liberated by 1 ml of sample.
In order to minimise the risk of failure in the pasteurisation process, the system should have an automatic control system for:
(1) *Pasteurisation temperature.* Temperature recorder and flow diversion valve at the outlet of the temperature holder for diverting the flow back to the balance tank in case of pasteurisation temperatures below the legal requirement.
(2) *Holding time at pasteurisation temperature.* Capacity control system which activates the flow diversion valve in case the capacity exceeds the maximum for which the holding tube is designed.

(3) *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 pasteurised side, thus preventing possible leakage of raw milk into the pasteurised milk.

Calculation of residence time in holding tube
The mean residence time (t) in the holding tube can be calculated as follows:

$$t = \frac{\text{length of tube} \times \text{volume per metre}}{\text{capacity per second}}$$

Values for volume per metre can be found in the table Volume in Stainless Steel Pipes.

The individual particles spend different times in the holding tube and this results in residence time variations. To avoid bacteriological problems, it is necessary to heat even the fastest particles long enough.
The holding tube must have an efficiency of at least 0.8 (tmin/tmean) and this can best be achieved by avoiding a laminar flow, ie, ensuring a turbulent flow at a Reynolds Number >12,000 and choosing a ratio of length (m)/dia-meter >200 for the holding tube.

Homogenisation

Milk products are usually homogenised to prevent creaming/separation during storage. Other dairy products are homogenised to improve water binding, reduce free fat etc. Homogenisation takes place in a high-pressure homogeniser, which is basically a positive pump equipped with a narrow slit called the homogenising valve. The milk is forced through the homogenising valve at high pressure and this process causes disruption of the fat globules as illustrated in fig. 1. Advanced types of homogenising valves have been constructed for optimum homogenising efficiency in various processes.

In a pasteurisation plant the homogeniser is typically placed upstream before the final heat treatment in a heat exchanger. Homogenisation of milk must take place at a temperature above the melting point of the milk fat. This means that the homogeniser is often placed after the first regenerative section.

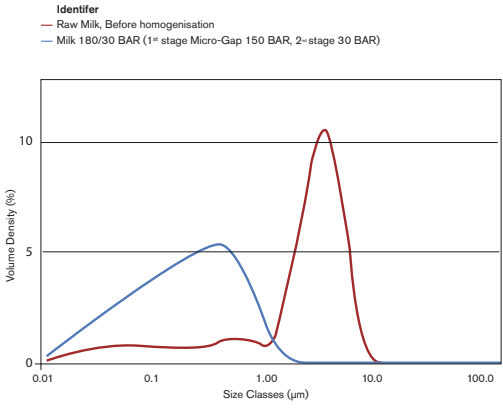


Fig. 1: The fat globule size distribution in milk before and after homogenisation at 180 BAR total pressure with 30 BAR on the 2nd stage (Malvern Mastersizer 3000, laser diffraction with MIE, volume weighted distributions).

In indirect UHT milk plants (fig. 3) the homogeniser is also generally placed upstream. However, in indirect UHT cream systems where the fat-content is higher than 10% (possibly as low as 6%), and in milk products with higher protein content, the homogeniser is preferably placed downstream.

In direct UHT systems the homogeniser is always placed downstream on the aseptic side after UHT treatment (fig. 4 and fig. 8).

Total homogenisation is most commonly applied for pasteurised milk and always used with UHT milk. The fat content is standardised prior to homogenisation. Two-stage homogenisation with a SEO or XFD homogenising valve or single-stage homogenisation with a LW homogenising valve at a total pressure of 140 – 180 BAR is most often applied for the requested stability of pasteurised milk. For UHT milk a total pressure of 200 – 250 BAR is applied. For high flow rates, two-stage homogenisation with the patented Micro-Gap homogenising valve is recommended. The Micro-Gap enables reduction of the total pressure by approx. 20 – 30% (fig. 2).

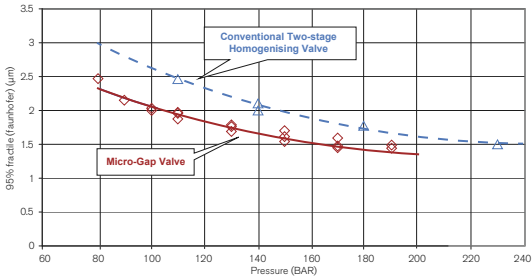


Fig. 2: Micro-Gap compared with conventional two-stage valve arrangement (95%-Fractile from volume-weighted fat globule size distributions, laser diffraction with Fraunhofer).

Another option for pasteurised milk is partial homogenisation in order to save investment costs as well as operating costs. This enables approx. 66% reduction of total power consumption during homogenisation as only approx. one third of the milk volume is passed through the homogeniser. Partial homogenisation is only applied for pasteurised milk (never for UHT milk or yoghurt). In partial homogenised milk 1/3 of the volume is homogenised cream with up to max. 12% fat, while 2/3 of the volume is skimmed milk, which is bypassed and added to the homogenised cream.

UHT/ESL Treatment of Milk

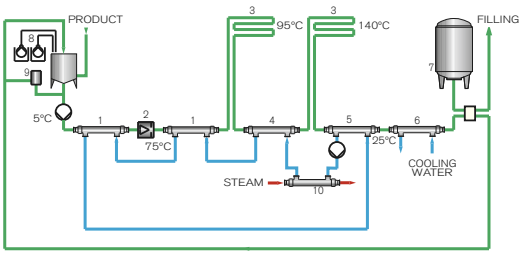
UHT/ESL

APV is focussed on being the leader within the UHT/ESL technology and has the largest product range within UHT:

Indirect:	Plate UHT Plant
	Tubular UHT Plant (Figure 3)
Direct:	Injection UHT Plant
	Infusion UHT Plant

In addition to the 4 main systems, APV has developed the following variations:

ESL - Extended Shelf Life
Pure Lac™
Combi UHT (2-4 systems in one)
High Heat Infusion
Instant Infusion



1. Tubular regenerative preheaters
2. Homogeniser
3. Holding tubes
4. Tubular final heater
5. Tubular regenerative cooler
6. Final cooler
7. Sterile tank
8. CIP unit
9. Sterilising loop
10. Water Heater

Fig. 3: Flow diagram for Tubular Steriliser

ESL - Extended Shelf Life

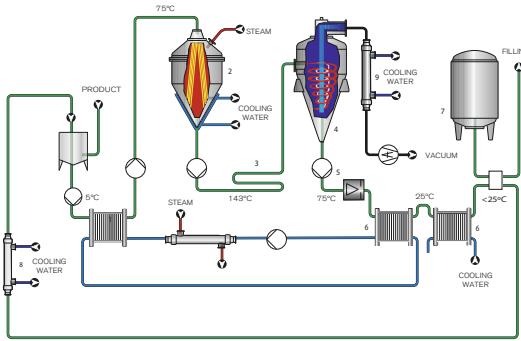
In many parts of the world the production of fresh milk presents a problem in regard to keeping quality. This is due to inadequate cold chains, poor raw material and/or insufficient process and filling technology. Until recently, the only solution has been to produce UHT milk with a shelf life of 3 -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

temperature. In order to try to improve the shelf life of ordinary pasteurised milk, various attempts have been made to increase the pasteurisation temperature and this led to the extended shelf life concept.

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

APV has during the last years developed a patented process where the temperature may be raised to as high as 140°C, but only for fractions of a second. This is the basis for the Pure-Lac™ process.

The APV infusion ESL is based on the theory that a high temperature/ultra short holding time will provide an efficient kill rate as well as a very low chemical degradation.



1. Plate preheaters
2. Steam infusion chamber
3. Holding tube
4. Flash vessel
5. Aseptic homogeniser
6. Plate coolers
7. Aseptic tank
8. Non aseptic cooler
9. Condenser

Fig. 4: Flow Diagram for Steam Infusion Steriliser

This means that a very high temperature for a very short time will result in a high-quality ESL product, with long shelf life and a taste like low pasteurised milk.

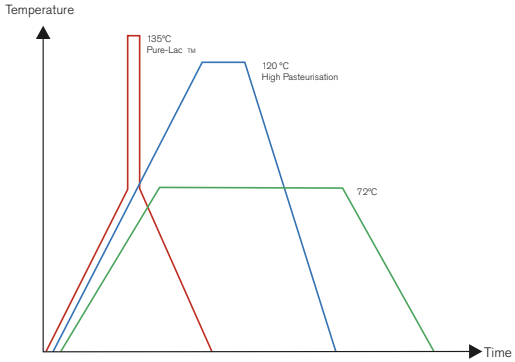


Fig. 5: Temperature profile for pasteurisation processes

The Pure Lac™ process

In co-operation with Elopak, APV has developed the Pure Lac™ concept which in a systematic way attacks the challenge of improving milk quality for the consumer.

Based on investigations of consumer requirements and the present market conditions in a larger number of countries, the objective of Pure Lac™ was defined as follows:

- A sensory quality equal to or better than pasteurised products
- A "real life" distribution temperature of neither 5°C, nor 7°C but 10°C
- A prolonged shelf life corresponding to 14 to 45 days at 10°C depending on filling methods and raw milk quality
- A method to accommodate changes in purchasing patterns of the consumer
- An improved method for distribution of niche products
- To cover the complete milk product range, i.e. milk, creams, desserts, ice cream mix, etc.
- To provide tailored packaging concepts designed to give maximum protection using minimum but adequate packaging solutions.

After reviewing the range of "cold technologies" available, it became obvious that most of them were only suited for white milk. Furthermore, the actual microbiological reduction rate for some of the processes was inadequate to provide sufficient safety for shelf life of more than 14 days at 10°C.

Process	Log. reduction aerobic, psycro-tropic spores	Extended shelf life max 4°C storage	Expected shelf life max 10°C storage
Pasteurisation	0	10 days	1 - 2 days
Centrifugation	1	14 days	4 - 5 days
Microfiltration	2 - 3	30 days	6 - 7 days
Pure Lac™ ESL pasteurisation	8	Over 45 days	Up to 45 days (**)
UHT process High Heat Process	8 (*) 40	180 days at 25°C	180 days at 25°C

* Thermophilic spores

** Depending on filling solution

UHT - Ultra High Temperature

All UHT processes are designed to achieve commercial sterility. This calls for application of heat to the product and a chemical sterilant or other treatment that render the equipment, final packaging containers and product free of viable micro-organisms able to reproduce in food under normal conditions of storage and distribution. In addition it is necessary to inactivate toxins and enzymes present and to limit chemical and physical changes in the product. In very general terms it is useful to have in mind that an increase in temperature of 10°C increases the sterilising effect 10-fold whereas the chemical effect only increases approximately 3-fold. In this section we will define some of the more commonly used terms and how they can be used for process evaluation.

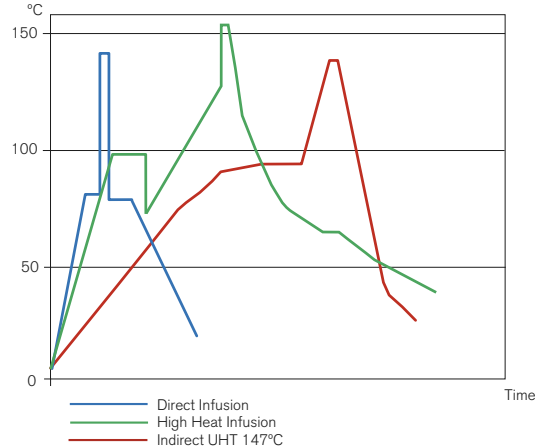


Fig. 6: Temperature profiles for direct infusion, high heat infusion and indirect UHT processes

The logarithmic reduction of spores and sterilising efficiency

When micro-organisms and/or spores are exposed to heat treatment not all of them are killed at once.

However, in a given period of time a certain number is killed while the remainder survives. If the surviving micro-organisms are once more exposed to the temperature treatment for the same period of time an equal proportion of them will be killed. On this basis the lethal effect of sterilisation can be expressed mathematically as a logarithmic function:

$K \cdot t = \log N/N_t$

where N = number of micro-organisms/spores originally present

N_t = number of micro-organisms/spores present after a given time of treatment (t)

K = constant

t = time of treatment

A logarithmic function can never reach zero, which means that sterility defined as the absence of living bacterial spores in an unlimited volume of product is impossible to achieve. Therefore the more workable concept of "sterilising effect" or "sterilising efficiency" is commonly used.

The sterilising effect is expressed as the number of decimal reductions achieved in a process. A sterilising effect of 9 indicates that out of 10^9 bacterial spores fed into the process only 1 (10°) will survive.

Spores of Bacillus subtilis or Bacillus stearothermophilus are normally used as test organisms to determine the efficiency of UHT systems because they form fairly heat resistant spores.

Terms and expressions to characterise heat treatment processes

Q_{10} value. The sterilising effect of heat sterilisation increases rapidly with the increase in temperature as described above. This also applies to chemical reactions which take place as a consequence of an increase in temperature. The Q_{10} value has been introduced as an expression of this increase in speed of reactions and specifies how many times the speed of a reaction increases when the temperature is raised by 10°C. Q_{10} for flavour changes is in the order of 2 to 3 which means that a temperature increase of 10°C doubles or triples the speed of the chemical reactions.
A Q_{10}value calculated for killing bacterial spores would range from 8 to 30, depending on the sensitivity of a particular strain to the heat treatment.

D-Value. This is also called the decimal reduction time and is defined as the time required to reduce the number of microorganisms to one-tenth of the original value, i.e. corresponding to a reduction of 90%.

z-Value. This is defined as the temperature change, which gives a 10-fold change in the D-value.

F_0 value. This is defined as the total integrated lethal effect and is expressed in terms of minutes at a selected reference temperature of 121.1°C. F_0 can be calculated as follows:

$F_0 = 10^{(T - 121.1)/z} \times t / 60$, where

T = processing temperature (°C)

z = z-value (°C)

t = processing time (seconds)

F_0 = 1 after the product has been heated to 121.1 ºC for one minute. To obtain commercially sterile milk from good quality raw milk, for example, an F_0 value of minimum 5 to 6 is required.

B and C* Values.* In the case of milk treatment, some countries are using the following terms:

- Bacteriological effect:
  B* (known as B star)

- Chemical effect
  C* (known as C star)

B* is based on the assumption that commercial sterility is achieved at 135ºC for 10.1 seconds with a corresponding z-value of 10.5ºC; this reference process is giving a B* value of 1.0, representing a reduction of thermophilic spore count of 10^9 per unit (log 9 reduction). The B* value for a process is calculated similarly to the F_0 value:

$B^* = 10^{(T - 135) / 10.5} \times t / 10.1$, where

T = processing temperature (ºC)

t = processing time (seconds)

The C* value is based on the conditions for a 3 percent destruction of thiamine (vitamin B_1); this is equivalent to 135ºC for 30.5 seconds with a z-value of 31.4ºC. Consequently the C* value can be calculated as follows:

$C^* = 10^{(T - 135) / 31.4} \times t / 30.5$

Fig. 6 shows that a UHT process is deemed to be satisfactory with regard to keeping quality and organoleptic quality of the product when B* is > 1 and C* is < 1.

The B* and C* calculations may be used for designing UHT plants for milk and other heat sensitive products. The B* and C* values also include the bacteriological and chemical effects of the heating up and cooling down times and are therefore important in designing a plant with minimum chemical change and maximum sterilising effect. The more severe the heat treatment is, the higher the C* value will be. For different UHT plants the C* value corresponding to a sterilising effect of B* =

1 will vary greatly. A C* value of below 1 is generally accepted for an average UHT plant design. Improved designs will have C* values significantly lower than 1.

The APV Steam Infusion Steriliser has a C* value of 0.15.

Residence time
Particular attention must be paid to the residence time in a holding cell or tube and the actual dimensioning will depend on several factors such as turbulent versus laminar flow, foaming, air content and steam bubbles. Since there is a tendency to ope-rate at reduced residence time in order to minimise the chemical degradation (C* value < 1) it becomes increasingly important to know the exact residence time.

In APV the infusion system has been designed with a special pump mounted directly below the infusion chamber which ensures a sufficient over-pressure in the holding tube in order to have a single phase flow free from air and steam bubbles. This principle enables APV to define and monitor the holding time and temperature precisely and makes it the only direct steam heating system, which allows true validation of flow and temperature at the point of heat transfer.

Commercial sterility
The expression of commercial sterility has been mentioned previously and it has been pointed out that complete sterility in its strictest sense is not possible. In wor-king with UHT products commercial sterility is used as a more practical term, and a commercially sterile product is defined as one which is free from micro-organisms which grow under the prevailing conditions.

Chemical and bacteriological changes at high temperatures
The heating of milk and other food products to high temperatures results in a range of complex chemical reactions causing changes in colour (browning), development of off-flavours and formation of sediments. These unwanted reactions are largely avoided through heat treatment at a higher temperature for a very short time. It is important to seek the optimum time/temperature combination, which provides sufficient kill effect on spores but, at the same time, limits the heat damage, in order to comply with market requirements for the final product.

Raw material quality
It is important that all raw materials are of very high quality, as the quality of the final product will be directly affected. Raw materials must be free from dirt and have a very low bacteria spore count, and any powders must be easy to dissolve.

All powder products must be dissolved prior to UHT treatment because bacteria spores can survive in dry powder particles even at UHT temperatures. Undissolved powder particles will also damage homogenising valves causing sterility problems.

Heat stability. The question of heat stability is an important parameter in UHT processing.
Different products have different heat stability and although the UHT plant will be chosen on this basis, it is desirable to be able to measure the heat stability of the products to be UHT treated. For most products this is possible by applying the alcohol test. When samples of milk are mixed with equal volumes of an ethyl alcohol solution, the proteins become unstable and the milk flocculates. The higher the concentration of ethyl alcohol is without flocculation, the better the heat stability of the milk. Production and shelf life problems are usually avoided provided the milk remains stable at an alcohol concentration of 75%.
High heat stability is important because of the need to produce stable homogeneous products, but also to prevent operational problems as e.g. fouling in the UHT plant. This will decrease running hours between CIP cleanings and thereby increase product waste, water, chemical and energy consumption. Generally it will also disrupt smooth operation and increase the risk of insterility.

Shelf life. The shelf life of a product is generally defined as the time for which the product can be stored without the quality falling below a certain minimum acceptable level. This is not a very sharp and exact definition and it depends to a large extent on the perception of "minimum acceptable quality". Having defined this, it will be raw material quality, processing and packaging conditions and conditions during distribution and storage which will determine the shelf life of the product.

Milk is a good example of how wide a span the concept of shelf life covers:

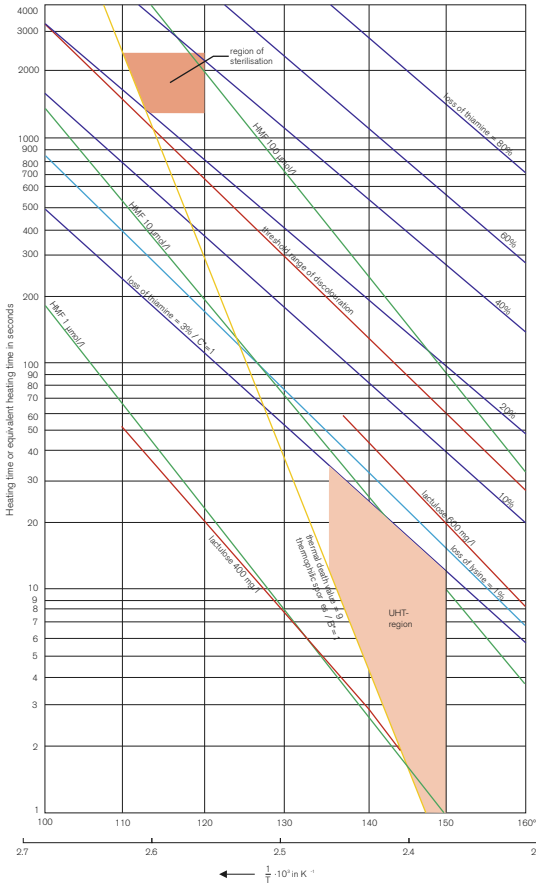


Fig. 7: Bacteriological and chemical changes of heated milk

Product	**Shelf life**	**Storage**
Pasteurised milk	5 - 10 days	refrigerated
ESL/Pure-Lac™	20 - 45 days	refrigerated
UHT milk	3 - 6 months	ambient temperature

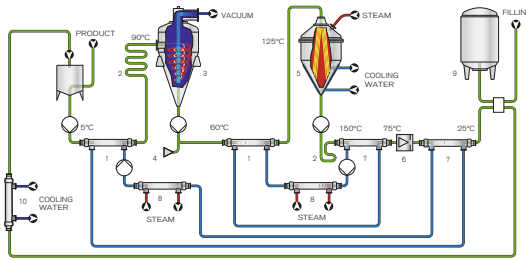
The usual organoleptic factors limiting shelf life are deteriorated taste, smell and colour, while the physical and chemical

limiting factors are incipient gelling, increase in viscosity, sedimentation and cream lining.

High Heat Infusion Steriliser

The growing incidents of heat resistant spores (HRS) is challenging traditional UHT technologies and setting new targets. The HRS are extremely heat resistant and require a minimum of 145 - 150°C for 3 - 10 seconds to achieve commercial sterility. If the temperature is increased to this level in a traditional indirect UHT plant it would have an adverse effect on the product quality and the overall running time of the plant. Furthermore, it would result in higher product losses during start and stop and more frequent CIP cycles would have to be applied. Using the traditional direct steam infusion system would result in higher energy consumption and increased capital cost. On this basis, APV developed the new High Heat Infusion system.

The flow diagram in fig. 8 illustrates the principle design including the most important processing parameters while fig. 8 shows the temperature/time profile in comparison to conventional infusion and indirect systems.
Note that the vacuum chamber has been installed prior to the infusion chamber. This design facilitates improvement in energy recovery and it is possible to achieve 75% regeneration compared to 40% with conventional infusion systems and 80 - 85% with indirect tubular systems. The kill rate is F_0 = 40 - 70.



1. Tubular preheaters
2. Holding tubes
3. Flash vessel (non aseptic)
4. Non aseptic flavour dosing (option)
5. Steam infusion chamber
6. Homogeniser (aseptic)
7. Tubular coolers
8. Tubular Heaters
9. Aseptic tank
10. Non aseptic cooler

Fig. 8: Flow diagram for High Heat Infusion Steriliser

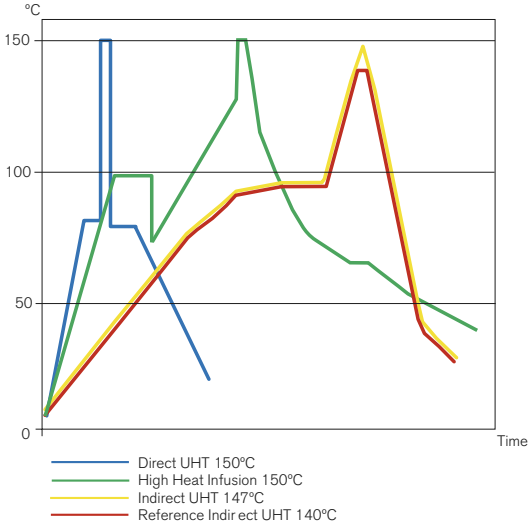


Fig. 9: Time/temperature profiles illustrating High Heat Infusion processing parameters

Butter

Composition of Butter

Butter must comply with certain regulations:

Fat	Min.	80%	(82%)
Moisture	Max.	16%	
Milk solids non-fat (MSNF)	Max.	2%	
Salt (NaCl):			
Mildly salted	approx.	1%	
Strongly salted	-	2%	
Acidity:			
Sweet cream butter	pH 6.7		
Cultured butter	pH 4.6		
Mildly cultured butter	pH 5.3		

Buttermilk normally contains:

Sweet buttermilk	0.5-0.7% fat
	approx. 8.5% MSNF
Cultured buttermilk	0.4-0.6% fat
	approx. 8.3% MSNF

Yields

1 kg butter can be made from:

approx. 20 kg milk with 4.2% fat
- 2.2 kg cream with 38% fat
- 2.0 kg cream with 42% fat

Buttermaking

Buttermaking may be carried out either as a batch process in a butter churn or as a continuous process in a continuous buttermaking machine.
In addition to cream treatment, buttermaking comprises the following stages:

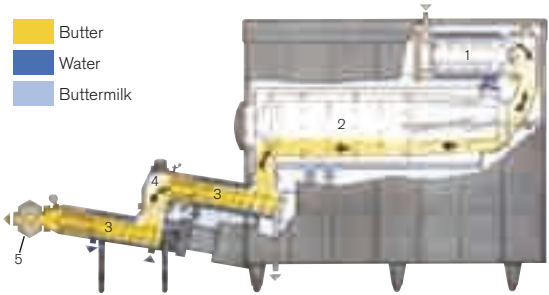
(1) churning of cream into butter grains and buttermilk;
(2) separation of butter grains and buttermilk;
(3) working of the butter grains into a cohesive mass;
(4) addition and distribution of salt;
(5) adjustment and distribution of moisture;
(6) final working, under vacuum, to minimise the air content.

A continuous buttermaking machine has existed for many years. It was invented by a German professor, Dr. Fritz. However, this machine was deficient in a number of respects. It

could be used only for the treatment of sweet cream, and there were problems with the production of salted butter.

APV manufactures continuous buttermaking machines with capacities ranging from 500 kg to 12,000 kg butter/hour.
The APV continuous buttermaking machine can produce all types of butter: cultured and sweet, salted and unsalted. Furthermore, the machine can produce butter according to the "NIZO" as well as to the "IBC" method. Blended products (e.g. Bregott) in which some of the butter fat has been replaced by vegetable fats can also be produced.
The APV continuous buttermaking machine also guarantees that products are of the highest possible quality, and that the operating economy is the best obtainable.
The APV continuous buttermaking machine is designed according to the following principles:

(1) The churning section is, in principle, designed in accordance with the system of Dr. Fritz. The section consists of a horizontal cylinder and a rotating beater. The beater velocity is infinitely variable between 0 and 1,400 rpm. Since the churning process lasts only 1-2 seconds, it is important to adjust the beater velocity to obtain optimum butter grain size. The moisture content of the butter and the fat content of the buttermilk also depend on the beater velocity.
(2) The separating section consists of a horizontal rotating cylinder. The velocity is infinitely variable.
The first part of the cylinder is equipped with baffle plates for further treatment of the mixture of butter grains and buttermilk which is fed in from the churning section.
The second part of the cylinder is designed as a sieve for buttermilk drainage. It is equipped with a very finely meshed wire screen, which retains even small butter grains. The buttermilk drainage from the butter grains is very efficient and the rotation of the strainer drum prevents butter clogging.
(3) The working section consists of two inclined sections (I and II) with augers for transport of the butler, and working elements in the form of perforated plates and mixing vanes. The velocity of each of the two sections is infinitely variable.
In the production of salted butter, a salt slurry (40-60%) is pumped into working section I where it is worked into the butter.



(1) Churning section
(2) Separating section
(3) Working section
(4) Vacuum chamber
(5) Butter pump

The above is a diagram of APV's continuous buttermaking machine.

Any adjustment of the moisture content also takes place in working section I. Water dosing is carried out automatically.
In order to reduce the air content in the butter from 5-6% or more to below 0.5%, a vacuum chamber has been inserted between working sections I and II. When the butter from working section I enters this chamber, it passes through a double perforated plate from which it emerges in very thin layers. This provides the best conditions for escape of air. The butter leaves the machine through a nozzle fitted at the end of working section II. Mounted on the nozzle is a butter pump, which conveys the butter to the butter silo.

Buttermaking according to the IBC method
(Indirect Biological Culturing)
This is a method for production of cultured butter from sweet cream. After sweet cream churning and buttermilk drainage, a so-called D starter, which has a high diacetyl (aroma) content, is worked into the butter. Also, lactic acid has been added to this starter, producing a pH reduction in addition to the aroma, Furthermore, an ordinary B starter is worked into the butter to obtain the correct moisture content. When salted butter is produced, the salt is mixed into the D starter.

A similar production method is the well known "NIZO" method. The above methods provide for more flexible cream treatment since the incubation temperatures for the starters do not have to be taken into account. Besides, the production of cultured buttermilk is avoided (sweet buttermilk is much more usable in other products than cultured buttermilk). Finally, butter produced according to this method has a longer shelf life.

Calculating Butter Yield

The yield of butter from whole milk can be calculated using the following equations. (Loss and overweight are not considered.).

$$\text{kg cream} = \frac{\text{kg milk} \times (\%\text{ fat in milk} - \%\text{ fat in skimmilk})}{\%\text{ fat in cream} - \%\text{ fat in skimmilk}}$$

$$\text{kg butter} = \frac{\text{kg cream} \times (\%\text{ fat in cream} - \%\text{ fat in buttermilk})}{\%\text{ fat in butter} - \%\text{ fat in buttermilk}}$$

If the fat percentage in skimmilk, buttermilk and butter is not known, the following estimated values rnay be used:

Skimmilk = 0.05% fat
Buttermilk = 0.4% fat
Butter = 82.5% fat

Churning Recovery

The churning recovery value (CRV) is equal to the amount of fat remaining in the buttermilk expressed as a percentage of the total fat content of the cream before churning. It can be worked out from the following equation:

$$\text{CRV} = \frac{(100\text{-}7/6 \times \%\text{ fat in cream}) \times \%\text{ fat in buttermilk}}{\%\text{ fat in cream}}$$

In other words, the only data required are the cream and buttermilk fat percentages.

Churning Recovery Table

% fat in cream	% fat in buttermilk								
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
30.5	0.21	0.42	0.63	0.85	1.06	1.27	1.48	1.69	1.90
31.0	0.21	0.41	0.62	0.82	1.03	1.24	1.44	1.65	1.85
31.5	0.20	0.40	0.60	0.80	1.00	1.21	1.41	1.61	1.81
32.0	0.20	0.39	0.59	0.78	0.98	1.18	1.37	1.57	1.76
32.5	0.19	0.38	0.57	0.76	0.96	1.15	1.34	1.53	1.72
33.3	0.19	0.37	0.56	0.75	0.93	1.12	1.31	1.49	1.68
33.5	0.18	0.36	0.55	0.73	0.91	1.09	1.27	1.46	1.64
34.0	0.18	0.35	0.53	0.71	0.89	1.07	1.24	1.42	1.60
34.5	0.17	0.35	0.52	0.69	0.87	1.04	1.21	1.39	1.56
35.0	0.17	0.34	0.51	0.68	0.85	1.01	1.18	1.35	1.52
35.5	0.16	0.33	0.50	0.66	0.83	0.99	1.16	1.32	1.49
36.0	0.16	0.32	0.48	0.64	0.81	0.97	1.13	1.29	1.45
36.5	0.16	0.31	0.47	0.63	0.79	0.94	1.10	1.26	1.42
37.0	0.15	0.31	0.46	0.61	0.77	0.92	1.08	1.23	1.38
37.5	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.35
38.0	0.14	0.29	0.44	0.59	0.73	0.88	1.03	1.17	1.32
38.5	0.14	0.29	0.43	0.57	0.72	0.86	1.00	1.14	1.29
39.0	0.14	0.28	0.42	0.56	0.70	0.84	0.98	1.12	1.26
39.5	0.14	0.27	0.41	0.55	0.68	0.82	0.96	1.09	1.23
40.0	0.13	0.27	0.40	0.53	0.67	0.80	0.93	1.07	1.20
40.5	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17
41.0	0.13	0.25	0.38	0.51	0.64	0.76	0.89	1.02	1.15
41.5	0.12	0.25	0.37	0.50	0.62	0.75	0.87	1.00	1.12
42.0	0.12	0.24	0.36	0.49	0.61	0.73	0.85	0.97	1.09
42.5	0.12	0.24	0.36	0.47	0.59	0.71	0.83	0.95	1.07
43.0	0.12	0.23	0.35	0.46	0.58	0.70	0.81	0.93	1.04
43.5	0.11	0.23	0.34	0.45	0.56	0.68	0.79	0.91	1.02
44.0	0.11	0.22	0.33	0.44	0.55	0.66	0.77	0.88	1.00
44.5	0.11	0.22	0.32	0.43	0.54	0.65	0.76	0.86	0.97
45.0	0.11	0.21	0.32	0.42	0.53	0.63	0.74	0.84	0.95

The result can also be taken from a table that has been worked out on the basis of Report No. 38 from the Danish Government Dairy Research Institute. See below.

Table for adjustment of Moisture Content in Butter

% water present	Addition of water in kg per 100 kg butter when the desired % moisture is as follows:					
	16.0	15.9	15.8	15.7	15.6	15.5
15.9	0.12					
15.8	0.24	0.12				
15.7	0.36	0.24	0.12			
15.6	0.47	0.36	0.24	0.12		
15.5	0.59	0.47	0.36	0.24	0.12	
15.4	0.71	0.59	0.47	0.36	0.24	0.12
15.3	0.83	0.71	0.59	0.47	0.35	0.24
15.2	0.94	0.83	0.71	0.59	0.47	0.35
15.1	1.06	0.94	0.82	0.71	0.59	0.47
15.0	1.18	1.06	0.94	0.82	0.71	0.59
14.9	1.29	1.18	1.06	0.94	0.82	0.71
14.8	1.41	1.29	1.17	1.06	0.94	0.82
14.7	1.52	1.41	1.29	1.17	1.06	0.94
14.6	1.64	1.52	1.41	1.29	1.17	1.05
14.5	1.75	1.64	1.52	1.40	1.29	1.17
14.4	1.87	1.75	1.64	1.52	1.40	1.29
14.3	1.98	1.87	1.75	1.63	1.52	1.40
14.2	2.10	1.98	1.87	1.75	1.63	1.52
14.1	2.21	2.10	1.98	1.86	1.75	1.63
14.0	2.33	2.21	2.09	1.98	1.86	1.74
13.9	2.44	2.32	2.21	2.09	1.97	1.86
13.8	2.55	2.44	2.32	2.20	2.09	1.97
13.7	2.67	2.55	2.43	2.32	2.20	2.09
13.6	2.78	2.66	2.55	2.43	2.32	2.20
13.5	2.89	2.78	2.66	2.54	2.43	2.31
13.4	3.00	2.89	2.77	2.66	2.54	2.43
13.3	3.11	3.00	2.88	2.77	2.65	2.54
13.2	3.22	3.11	3.00	2.88	2.77	2.65
13.1	3.34	3.22	3.11	2.99	2.88	2.76
13.0	3.45	3.33	3.22	3.10	2.99	2.87
12.9	3.56	3.44	3.33	3.22	3.10	2.99
12.8	3.67	3.56	3.44	3.33	3.21	3.10
12.7	3.78	3.67	3.55	3.44	3.32	3.21
12.6	3.89	3.78	3.66	3.55	3.43	3.32
12.5	4.00	4.89	3.77	3.66	3.54	3.43
12.4	4.11	4.00	3.88	3.77	3.65	3.54
12.3	4.22	4.11	3.99	3.88	3.76	3.65
12.2	4.33	4.21	4.10	3.99	3.87	3.76
12.1	4.44	4.32	4.21	4.10	3.98	3.87
12.0	4.55	4.43	4.32	4.21	4.09	3.98

Adjusting Moisture Content in Butter

Conventional Churns

The churning of the cream should be carried out in such a way that the moisture content of the butter is slightly below the maximum permitted amount. A test of the moisture content should be made as soon as the butter has been worked sufficiently.

When the amount of butler is known, the table above can be used.

If desired, the following equation may also be used:

$$\text{kg water to be added} = \frac{\text{kg butter} \times (\%\ \text{MD} - \%\ \text{MP})}{100 - \%\ \text{MP}}$$

where: MD = Moisture desired
MP = Moisture present

Continuous Buttermaking Machines

The churning of the cream should be carried out in such a way that the moisture content of the butter - without any addition of water - is below the maximum permitted amount.

The moisture content of the butter and the regulation of the water dosing pump will normally be automatically controlled.

When salted butter is manufactured, a salt slurry is continuously dosed into the butter. This, however, will increase the moisture content of the butter, reducing the amount of water to be added.

Determination of Salt Content in Butter

There are several ways of determining the salt content of butter. The analysis can most conveniently be carried out with a 10-gramme sample that has already been used for determination of the moisture content of the butter.

The butter is melted and poured into a 150 ml beaker. The butter residue is washed into the beaker by means of 50-100 ml of water at 70°C. After addition of 10 drops of saturated potassium chromate solution, titration takes place with the use of a 0.17 n silver nitrate solution ($AgNO_3$), added gradually until the colour changes from yellow to brownish. The salt content is then determined in accordance with the following equation:

ml of silver nitrate solution used x 0.1 = percentage of salt.

Iodine Value and Refractive Index

The iodine value is defined as the number of grammes of iodine that can be absorbed in 100 g butterfat. The refractive index

stales the angle of refraction measured in a so- called refractometer, when a ray of light passes from the air through melted butterfat. Both the iodine value and the refractive index are an indication of the content of unsaturated fatty acids (the most important being oleic acid), which have a lower melting point than saturated fatty acids.
The relation between the iodine value and the refractive index is given in the table below.

	Iodine value	Refractive Index
Hard fat	26	40.6
	27	40.9
	28	41.2
	29	41.4
	30	41.7
	31	42.0
	32	42.2
	33	42.5
	34	42.7
	35	43.0
	36	43.3
Soft fat	37	43.5
	38	43.8
	39	44.1
	40	44.3
	41	44.6
	42	44.8

Fluctuations in Iodine Value and Temperature Treatment of Cream

Milk fat contains, on average, 35% oleic acid (iodine value approx. 35), but this percentage is subject to large seasonal fluctuations: the iodine value is high in the summer and low in the winter.
The iodine value depends primarily on the fat content of the feed and on the composition and melting point of this fat. It is therefore possible to influence the iodine value and thereby the firmness of the butter through feeding. It is usually difficult to regulate the various ingredients that make up coarse feed. Roots, for example, give hard and
brittle butter, while grass and hay give butter of a good consistency. On the other hand, concentrated feed should be chosen only after taking into account the fat content and particularly the composition of the fat (iodine value). For example, feeding with soya beans, linseed and rape seed cakes, etc, gives

butterfat with a high iodine value, whereas the iodine value is lower when feeding with coconut and palm cakes.
Other conditions being equal, Jersey cows yield butterfat with a lower iodine value than, for example, Holsteins, but this difference can be adjusted by choosing the right feed. By means of temperature treatment of the cream, it is possible to change the structure of the butter in order to improve its consistency. The temperatures used should be determined partly on the basis of the iodine value of the butterfat and partly on the basis of the temperature at which the butter will be consumed. It is therefore necessary for the creamery to know the iodine value of the butterfat used, and this value should be determined once a month.
In periods with iodine values above 35, the 19-16-8 method or a modification, for example, 23-12-8, should be used.
In periods with iodine values below 32, the 8-19-16 method or a modification, for example, 8-20-12, should be used.
In transitional periods (iodine values between 32 and 35), a 12-19-12 treatment can be used in the autumn, whereas in the spring, the normal high iodine treatment should be started straightaway.

Cheese

Cheese Varieties

It would be an almost impossible task to list all cheese types. In general, we distinguish between two basic cheese classes: Yellow and white cheese, where yellow cheese is cheese produced from cow's milk and white cheese is cheese produced from ewe's and goat's milk, in which the fat does not contain carotene.
Below are possible classifications of cheese types:

Extra hard cheese:	Parmesan, Goya, G
Hard cheese:	Emmental, Cheddar, etc.
Semi-hard cheese:	Gouda, Samsoe, Fontal, etc.
Semi-soft cheese:	Tilsit, Danbo, Butterkäse, Limburger, etc.
Soft cheese:	Port Salut, Bel Paese, Feta, etc.
Pasta Filata:	Mozzarella, Pizza Cheese, Provolone, Kashkaval, etc.
Mould cheese:	Blue veined cheese: Stilton, Roquefort, Danablu. White surface ripened cheese: Camembert, Brie.
Fresh cheese:	Unripened cheese: Queso Fresco, Quarg, Cottage Cheese etc.

However, many cheeses are characterised solely by their name. As an addition, the fat content of the cheese is often indicated, and very rarely the content of total solids (TS) in the cheese is also stated.
The fat content of the cheese states the fat in the cheese as a percentage of the TS content (50+, 45+, 30+, 20+). Furthermore, the designations "Full-Fat", "Reduced Fat" and "Half Fat" are used, which means that the cheeses contain 50-53% fat in TS, 36-39% fat in TS and 26-29% fat in TS respectively. The TS content of the cheese normally varies between 65% (Cheddar) and 40% (Feta), but it is constant for each type of cheese.

Cheese making

The feature common to all cheesemaking is that rennet is added to the milk, rennet being an enzyme that makes the milk coagulate and the coagulum contract, which, in turn, causes whey exudation, so-called syneresis.
Thus, the cheesemilk is separated into curd (cheese) and whey.

CHEESE:	10-15% of the milk
Fat:	89-94% of the milk fat
Protein:	74-77% of the milk proteins
	approx. 100% of the milk casein
WHEY:	85-90% of the milk
Fat:	6-11% of the milk fat
Protein:	23-26% of the milk proteins, incl. NPN*
MSNF**:	6.5% of whey is MSNF

* non-protein nitrogen
** milk solids non-fat

Standardisation of Cheese milk and Calculation of Cheese Yield

The standardisation of cheesemilk has two separate objectives:
(1) To obtain cheese with a composition that complies with the agreed standards.
(2) To obtain the most economic use of milk components consistent with consumer demands.

The two main elements in the standardisation of the fat percentage of cheese milk are:
(1) The protein percentage of the cheesemilk. The higher the protein percentage, the higher the fat percentage.
(2) The fat content required in the desired cheese type.

The table below can be used as a guideline for fat standardisation.

Whole milk		45% fat in TS		40% fat in TS		30% fat in TS		20% fat in TS		10% fat in TS	
% fat	% protein	% fat in cheesemilk	% whole milk	% fat in cheesemilk	% whole milk	% fat in cheesemilk	% whole milk	% fat in cheesemilk	% whole milk	% fat in cheesemilk	% whole milk
4.3	3.55	3.20	75	2.75	64	1.71	39	1.03	23	0.51	10.8
4.2	3.50	3.20	76	2.70	64	1.69	40	1.02	23	0.51	11.0
4.1	3.45	3.15	77	2.70	65	1.67	40	1.01	24	0.50	11.1
4.0	3.40	3.10	77	2.65	66	1.65	40	1.00	24	0.50	11.2
3.9	3.35	3.05	78	2.60	67	1.65	41	1.00	24	0.49	11.3
3.8	3.30	3.05	80	2.60	68	1.60	41	0.95	24	0.49	11.6
3.7	3.25	3.00	81	2.55	69	1.60	42	0.95	24	0.48	11.6
3.8	3.20	2.95	82	2.50	70	1.55	42	0.90	24	0.47	11.7
3.5	3.15	2.95	84	2.50	71	1.55	43	0.90	25	0.47	12.0

Example 1:
The cheesemilk contains: 3.3% protein
The cheese is to contain: 45% fat in TS
In the column "Whole milk" of the table, a value of 3.3% protein is found. From the column "45% fat in TS" it appears that the milk must be standardised to a fat content of 3.05%.

In case the protein content of the milk is not known, it is possible to make an approximate calculation of the protein percentage of the milk by using the following equation:

0.5 x fat% + 1.4 = protein%

thus, for example,

0.5 x 3.8% + 1.4 = 1.9 + 1.4 = 3.3% protein.

The table is arranged in such a way that it can also be used in case only the fat content of the non-standardised milk is known.

Example 2:
The non-standardised milk contains: 4%fat
The cheese is to contain: 40% fat in TS

In the column "Whole milk" of the table, a value of 4.0% fat is found. From the column "40% fat in TS" it appears that the

milk must be standardised to 2.65% fat. Furthermore, it can be seen that this is obtained by mixing 66% non-standardised milk with a fat content of 4.0% with 34% skimmilk.

Cheese samples should be analysed regularly to make sure that the cheesemilk has contained the correct percentage of fat, and this should be adjusted on the basis of the chemical composition of the milk, which varies with the seasons.
It is important that care is taken when stirring the cheese-milk and when carrying out the fat analysis, as a reading error of 0.1% means an error of 1.5% fat in TS in a 45% cheese, and more in cheeses of the low-fat type.
If samples are taken for analysis of fresh, unsalted cheese, it must be taken into account that the salt increases the TS in the cheese by approximately 2%, reducing the fat in TS by approximately 1.5%.
The final determination of fat in TS can only be carried out after 4-6 weeks when the salt has spread throughout the cheese, but even then, variations of more than 1% fat in TS can be found in cheeses from the same vat. It is therefore advisable to operate with a safety margin of at least 1% for ripened cheese and consequently 1.5% more for the fresh cheese.
Instead of using the table for adjusting the fat content in the cheesemilk, the actual fat percentage can be calculated. Several equations can be used for this calculation, but the one used in the following gives a very high degree of accuracy.

(1) *Cheese to be produced:*

Moisture	41.5%
Fat in TS	51.0%
Salt (NaCl)	1.5%

(2) *Raw milk:*

Fat	4.0%
Protein	3.4%

(3) *Retention figures:*

Fat	91.0%
Protein	76.5%
Protein in MSNF in cheese	87.6%

(4) *Calculations:*

(4.1) Cheese	100.0%	=	1,000.0 g
Moisture	41.5%	=	415.0 g

TS	58.5%	=	585.0 g
Fat in TS	51.0%	=	298.4 g
Solids non-fat		=	286.6 g
Salt (NaCl)	1.5%	=	15.0 g
MSNF		=	271.6 g
Protein in MSNF	87.6%	=	237.9 g

(4.2) Kg milk/kg cheese:

	Fat		*Protein*	
1,000 g cheese:	298.4 g =	91%	237.9 g =	76.5%
Whey:	29.5 g =	9%	73.1 g =	23.5%
Cheesemilk:	327.9 g =	100%	311.0 g =	100.0%

$$\text{Protein in fat-free milk} = \frac{3.4 \times 100}{(100 - 4)} = 3.54\%$$

Per 1,000 g cheese:

$$\text{Fat-free milk} = \frac{311.0 \times 100}{3.54} = 8{,}785.3 \text{ g}$$

Fat = 327.9 g
Cheesemilk = 9,113.2 g

= 9.1132 kg milk/kg cheese

(4.3) Fat percentage in cheesemilk:

$$\frac{327.9 \times 100}{9.113} = 3.60\%$$

(4.4) Cheese yield:

$$\frac{100}{9.113} = 10.97\%$$

Equations often used for the calculation of cheese yields are:

Cheddar $$Y = \frac{(0.9\,F + 0.78\,P - 0.1) \times 1.09}{1 - M}$$

Mozzarella: $Y = \frac{(0.88\ F + 0.78\ P - 0.02) \times 1.12}{1 - M}$

Cheddar $Y = \frac{(0.77\ F + 0.78\ P - 0.2) \times 1.10}{1 - M}$

where: Y = Yield in per cent
F = Fat percentage in milk
P = Protein percentage in milk
M = Moisture per kg cheese, 38% = 0.38 kg

Cheese yield is influenced by the loss of fat and curd fines in the whey. However, with modem production equipment and correct processing technology, it is possible to reduce the fat loss to less than 7.0% and the loss of curd fines to approx. 100 mg/kg whey.

Utilisation Value of Skimmilk in Cheesemaking

For this calculation, the figures from the cheese yield calculation are used as an example:

kg cheesemilk per kg cheese..... 9.1132
kg fat in cheesemilk..... 0.3279

kg skimmilk..... 8.7853

kg fat in whey 0.0295
kg whey..... 9.1132 -1.000 = 8.1132

fat in whey..... $\frac{0.0295 \times 100}{8.1132} = 0.36\%$

The fat in whey may be reduced to 0.05% by means of separation.

In the following example, the values used are:
Cheese = 23.00 krone/kg*
Whey = 0.30 krone/kg
Butter fat = 27.00 krone/kg

* 1 Danish krone = 100 øre

Income per kg cheese:
1 kg cheese..... 2,300.0 øre
8.11 kg whey at 30 øre/kg .... 243 øre

fat from whey separation:

$$\frac{8.11 \times (0.36 - 0.05)}{100} \times 2.700 = 69.0 \text{ øre} \quad 2{,}612.0 \text{ øre}$$

Costs per kg cheese:

butter value 0.3279 x 2,700 = ..	885.0 øre	
operating costs	500.0 øre	
whey separation 8.11 x 0.986 =	8.0 øre	1,393.0 øre
Value of skimmilk per kg cheese		976.2 øre

Utilisation value of skimmilk ...

$$\frac{1{,}219.0}{8.7853} = 138.8 \text{ øre}$$

Strength, Acidity and Temperature of Brine for Salting

The saturated brine which is normally used for salting cheese occasionally produces too hard a rind, but this can be counteracted by using a weaker solution. The solution should, however, contain at least 20% salt, corresponding to 10°BÈ. The strength of the brine should be checked every day: otherwise there is a risk that the solution may become too weak. If this happens, the cheese protein exuded through the whey will quickly decompose, and the increase in the growth of bacteria will cause defects not only in the rind but also in the interior of the cheese.

The strength of the brine should be measured with a hydrometer indicating degrees Baumè. When the brine has been in use for a certain time, the hydrometer will show a deviation of 1-2°BÈ because of the substances dissolved in the brine. In practice, this means that, when measuring the strength of a 2-3 months old brine solution, degrees Baumè can be considered equal to the salt percentage.

The acidity of the brine should be about the same as that of the cheese, i.e. approx. pH 5.2, but in a freshly made solution it will usually be somewhat higher depending upon the acidity of the water supply. It will usually take a week for the acidity to fail to the desired pH level, but to avoid any risk of damaging the cheese rinds during this time, the pH value should immediately be brought to the desired level by the addition of hydrochloric acid to the solution. By means of a simple analysis of the creamery's water supply, any laboratory will be able to state the amount of hydrochloric acid required.

The temperature of the brine, in particular, controls the speed at which the salt is absorbed by the cheese, and should be 10-

12°C the whole year round. It is therefore often necessary to cool the brine in the summer and heat it in the winter.
Strictly speaking, brine can be used for an indefinite time provided that the content of saltpetre (KNO_3) or bacteria and moulds does not become too high.
If the brine contains considerably more than 100,000 bacteria or moulds per ml, it should be sterilised by boiling or by adding 1/2 litre sodium hypochlorite per 1,000 litres brine. Sodium hypochlorite can also be added regularly once a month, and this will ensure that the content of harmful bacteria in the brine is kept low. When used for the manufacture of rindless cheese, the brine should be sterilised regularly.

Membrane Filtration

Definitions

Membrane filtration processes are pressure-driven molecular separation processes to obtain either concentration, fractionation, clarification and/or even a sterilisation of a liquid. The separation is determined by the membrane characteristics (molecular weight cut-off value – MWCO) and the molecular size of the individual components present in the liquid.

Membrane filtration changes the volume and/or the composition of a liquid, as the feed is divided into two new liquids of altered chemical/microbiological composition:
1) the *retentate* (what is rejected and concentrated by the membrane, e.g. proteins) and
2) the *permeate* (i.e. filtrate, what is passing through the membrane, e.g. water and minerals).

The volume of permeate produced by a certain membrane surface area per hour is called *flux* (measured in $l/m^2/h$ or simply "lmh"). The *volumetric concentration factor (VCF or CF)* is the ratio between the incoming feed volume and the outcoming retentate volume.
Rejection is 100%, when the component is fully concentrated by the membrane (cannot pass the membrane), and the rejection is 0%, when the component passes freely through the membrane, giving an identical concentration on both sides of the membrane.

The driving pressure is the *transmembrane pressure (TMP),* which is the pressure difference between the mean pressure on the retentate side (high) and the mean pressure on the permeate side (low or zero).

All membrane filtration processes are *cross-flow filtration* (feed flow parallel to the membrane surface, also called tangential flow), since a high velocity and shear rate across the membrane surface is essential to prevent build-up of retained materials, which reduces run times and flux and may alter the separation characteristics. High cross-flow velocities are especially important in UF and MF systems.

Membrane Processes

Concentration: In true concentration all total solids are retained since only water can pass through the membrane (as in evapo-

ration and drying processes). Example: Reverse Osmosis (RO).

Fractionation: Changing the chemical composition by concentrating some components, while others remain unchanged. Example: Nanofiltration (NF), Ultrafiltration (UF), Microfiltration fractionation (MFF).

Clarification: Changing a turbid liquid into a clear solution by removing all suspended and turbid particles. Example: Ultrafiltration (UF) and Microfiltration (MF)

Sterilisation: Removing all microorganisms from a liquid. Example: Microfiltration (MF).

Reverse Osmosis

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

Low molecular components like organic acids and NPN-components are not fully rejected by the membrane, especially when they appear uncharged (non-ionic), typically in acidic environments. This is the reason why COD levels in the permeate are higher processing acid products (e.g. lactic acid whey) compared to sweet products (e.g. sweet whey).

Max. achievable solids by RO are in the range of 17-23% TS for whey and UF permeates.

	RO	NF	UF	MFF	MF
Pore size (nm)	0.1 - 1	0.5 - 2	5 - 100	50 - 200	800 - 1400
MWCO	< 100	100 - 500	5,000 - 20,000		
Typical pressure (bar)	30 - 40	20 - 30	3 - 8	0.1 - 0.8	0.1 - 0.8
Typical temp. (°C)	10 - 30	10 - 30	10 or 50	50	50
Applications	Concentration	Demineralisation/ concentration	Protein concentration (WPC/MPC)	Protein fractionation Whey fat removal (WPI)	Bacteria removal Cheese milk ESL milk

Nanofiltration

Nanofiltration is very similar to the RO process, but the NF membranes are slightly more open than in conventional reverse osmosis. Nanofiltration allows passage of monovalent ions like Na^+, K^+ and Cl^-, whereas divalent ions like Mg^{++} and Ca^{++} are rejected by the membrane. In this way the nanofiltration process *demineralises* the feed by typical 30-40%. The degree of demineralisation is the %removal of minerals (or ash) from the feed to the permeate. Since some of the monovalent ions are removed from the retentate, the osmotic pressure will be lower than for conventional RO. For this reason it is possible to obtain higher %TS in the retentate compared to the RO process.

Max. achievable solids by NF are in the range of 21-25% TS for whey and UF permeates.

Example of NF mass balance of UF permeate from chee-se whey (indicative):

Nanofiltration	UF permeate	Retentate	Permeate
True protein%	0.01	0.04	0.0
NPN%	0.2	0.4	0.1
Lactose%	4.6	16.0	0.2
Acids%	0.2	0.6	0.02
Total ash%	0.5	1.0	0.3
Total solids%	5.5	18.0	0.6
Capacity kg/h	10,000	2,820	7,180

Ultrafiltration
Ultrafiltration has many applications, but basically it is a process for concentration of protein (and milk fat).

In the dairy ingredients industry UF is used for concentration of whey proteins from whey into *WPC* products or for concentrating milk proteins from skim milk into *MPC* products. The protein content may be concentrated up to 23-27% protein, and in many cases the retentate can be spray dried directly without an evaporation step. *Diafiltration* is necessary for higher purity products like WPC 80 (80% protein in the powder or in the solids). In diafiltration, water is added to the retentate to increase "washing out" of dissolved substances like lactose and minerals to the permeate.

UF of whey for the production of WPC retentates (a fat removal step is essential for producing WPI):

Composition	Whey	WPC 35	WPC 55	WPC 70	WPC 80	WPI 90
Protein%	0.8	3.3	08.3	17.9	23.3	23.3
Lactose%	4.6	4.9	4.7	4.0	1.7	1.3
Ash%	0.5	0.5	0.7	1.0	0.9	0.5
Fat%	0.06	0.3	0.8	1.7	2.3	0.2
TS%	6.0	9.0	14.5	24.7	28.1	25.4
VCF ratio	1x	5x	13x	29x	38x	38x
Diafiltration	-	-	-	-	+	+

Ultrafiltration of cheese milk
Protein standardisation: The protein content in the cheese milk is increased (e.g. from 3.2% up to 4.0-4.5%). When this method is used, traditional cheesemaking equipment may be used after UF and the cheesemaking technology involved is largely the same as that used in the traditional cheesemaking. The advantages of this method are savings in cheese rennet, and higher and more standardised cheese yields (throughput capacity) in existing cheese equipment.

Total concentration: Total concentration is a process in which the TS content in the retentate and in the fresh cheese is the same, i.e. a cheese process without whey drainage. This method is used for fresh cheeses like Quarg, Cream Cheese, Queso Fresco and Cast Feta. Ymer, Yoghurt and Pate Fraiche may also be produced by total UF concentration.

Microparticulation and LeanCreme™

Microparticulation is a thermal and mechanical treatment process that is used to denature whey protein concentrate (WPC) and form ideal protein particle sizes similar to fat globules in milk. Due to the increasing demand for reduced-fat products, microparticulated whey protein is an attractive option in the dairy and food industries to enhance taste and texture in reduced-fat products, and also as a multi-functional protein source.

APV has developed a unique microparticulation process, the APV LeanCreme™ process that comprises an ultrafiltration system for the production of WPC and a microparticulation system. The APV LeanCreme™ process is designed for optimum denaturation and results in a product called LeanCreme™. In more detail, the LeanCreme™ process comprises a plate heat exchanger (PHE) for preheating the WPC and a number of ASA's (APV Shear Agglomerators – purpose-built, scraped surface heat exchangers), a holding tube, an ASA for the first cooling, and a PHE for the second cooling in the regeneration section. During the APV LeanCreme™ process the particle size is controlled very accurately by the ASA's.

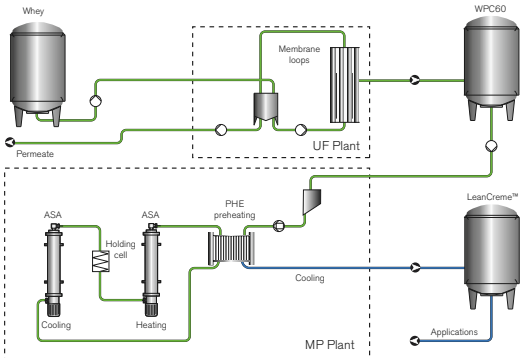


Fig. 10: The APV LeanCreme™ process

Particle size distribution

LeanCremeTM particle quality is mainly a question of particle size distribution, which is determined and controlled in the process. The curves in the graph below show how the ASA speed has a direct influence on the characteristics of two different LeanCreme™ qualities.

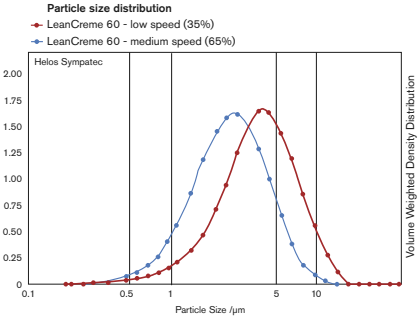


Fig. 11: Particle size distribution

Degree of denaturation
The quantity of LeanCreme™ particles is measured by the degree of denaturation.

This is defined as:

$$\text{Degree of denaturation} = \frac{\text{(Total protein (TOP) - Non casein nitrogen (NCN))}}{\text{(Total protein (TOP) - Non casein nitrogen (NCN))}} \times 100$$

In other words, the degree of denaturation is the percentage of aggregated proteins divided by the true proteins.

Types of LeanCreme™
The below table shows the different feed sources (WPC's) resulting in the different types of LeanCreme™:

	Feed Source – WPC28 to WPC80					
	Sweet cheese whey WPC	Lactic acid whey WPC	Acid casein whey WPC	Ideal whey WPC	Milk fat/ vegetable oil WPC	Casein/ whey WPC
LeanCreme™ Neutral	X					
LeanCreme™ Lactic	X	X*				
LeanCreme™ Acid	X		X			
LeanCreme™ Ideal				X		
LeanCreme™ Plus					X	
LeanCreme™ Mix						X

** Lactic acid whey WPC originating from thermo quarg whey is not recommended. The reason is the small quantity of whey proteins left after the cheese heating process. The resulting lactic acid whey contains a high amount of NPN, which cannot be transformed into LeanCreme™ particles.*

The range of WPC grades that can be microparticulated lies within WPC28 to WPC80.

Applications
The LeanCreme™ is applicable in the following four segments: Cheese, white line (fresh dairy products), ice cream and whey-based ingredients.

The APV LeanCreme™ process results in a product with superior functionality and physical properties. This has been proven in several tests comparing APV LeanCreme™ to other microparticulated products.

Characteristics and Advantages
APV LeanCreme™ has a creamy mouth feel due to the particle size, the viscosity increase and the functional and binding properties in different food systems. Furthermore, it has high water binding properties. The functional properties are maintained as the product is made in only one process step, thus avoiding overprocessing. One of the really important advantages is superior accuracy in particle size distribution, which is especially important for a high recovery degree in cheese and optimal function in general. The recovery of LeanCreme™ in cheese is approx. 75-82% which has been verified in actual plants. The recovery is limited by the content of NPN and GMP (glyco macro peptide). These two proteins are not affected by heat and can therefore not be transformed into LeanCreme™ particles.

A constant product quality is ensured via a high reproducibility of particle size distribution. Flexible particle size distribution enables customisation of LeanCreme™ products for different applications, e.g. yoghurt and ice cream with particle sizes of 1 to 2 microns and cheeses with particle sizes of 5 microns.

Finally, APV LeanCreme™ has excellent texture and taste in both low-fat and full-fat cheese after maturation, which has been verified from actual plants.

Microfiltration
Basically, there are two microfiltration processes: Bacteria removal/"cold sterilisation" (MF) and fractionation (also called microfiltration fractionation – MFF). In microfiltration applications it is important to operate with low TMP (< 1 bar).

Bacteria removal (MF)
In "cold sterilisation" using ceramic membranes with 0.8 -1.4 micron pore size, it is possible to achieve a 3.0-4.0 log reduction of total plate counts. Feed liquids which can be processed are skim milk, whey and WPC. Whole milk can- not be microfiltered due to the presence of milk fat globules, which may block the MF pores. Since only bacteria are removed, this means theoretically no fractionation takes place. However, aggregated protein particles/mi-celles and large fat globules may be partially rejected by the membrane.

With MF it is possible to produce ESL milk with shelf life up to 28 days at 5°C, or to combine MF with HHT/UHT processes, where the UHT thermal load can be reduced (since MF remove HRS spores) to make new types of market milk products. For cheese milk, MF is used to remove Clostridia spores so nitrate addition to the cheese milk can be avoided. For raw milk cheese (of non-pasteurised milk), MF operating at < 40°C removes critical patogenic bacteria like Listeria and Salmonella by app. 3-3.5 log reduction.

Cheese brine can also be clarified and sanitised, but for this application SW/organic membranes are often used instead of ceramics. Cheese brines may often contain a large number of yeast and mould, but by means of MF the content can be reduced to < 10/ml without changing the chemical composition of the brine (which happens during pasteurisation).

Fractionation (MFF)
In the protein fractionation processes using ceramic or organic membranes with 0.1-0.2 micron pore size, large proteins (casein micelles) are separated from the small soluble proteins (whey proteins). In this way it is possible to concentrate the micelles, which may have applications in production of cheese, fermented products and modified MPC powder. It may be possible to produce caseinate only using membranes.

In the whey-defatting process similar membranes are used to remove all fat and aggregated whey proteins from whey or WPC products so as to produce WPI products with less than 1% fat in the powder. Since the pore size is very small for fractionation processes, the permeate is theoretically sterile.
During the defatting process, a protein loss to the retentate should be expected. The protein recovery may be in the range of 70-85%. APV holds a patent to increase the recovery (> 85%).

APV presently holds four patents in MF applications:
1) special handling of retentate to avoid heat treating
2) special MF module (UTP design) made solely of stainless steel
3) double microfiltration to increase food safety
4) whey defatting with high protein recovery

Pre-treatments
Membranes (especially SW elements) are sensitive to suspended particles, and cleaning of the membranes may be difficult if these particles are not removed before the membrane filtration plant. Therefore a clarification step for whey is necessary to remove cheese fines, and a separator is necessary to remove whey fat. It is also recommended to pasteurise the feed to prevent high bacteria counts in the retentate. A bag filter or metal strainer may also be installed to protect membranes from large particles in the feed.

Calcium phosphate precipitation may occur when concentrating dairy liquids. This phenomenon can be prevented by lowering the pH (pH adjustment to 5.9-6.0), reducing temperature and avoiding high VCF.

Capacity, Run Time and Fouling
A membrane is always exposed to fouling, which will lower the permeate flux and thus the plant capacity. In RO/NF processes this fouling may be compensated by gradually increasing the pressure (TMP) to ensure constant plant capacity. This is more difficult for UF membranes, since raising the feed pressure will increase the flux for a short period only, after which it drops back again to the level obtained before the feed pressure was raised. A UF plant may start up at 20-50% higher capacity than the designed, average capacity. Usually after 3-4 hours the average capacity is reached and in the remaining production time, the flux decrease will be less significant. To obtain constant capacity, overflowing of initial surplus permeate into the feed tank or putting some loops on hold are ways of compensating for the fouling and the reduced plant capacity. Microfiltration plants are usually operated at a constant capacity, since the TMP is minimised to avoid fouling.

Run times are usually 8-10 hours for warm processes (50°C) and 16-20 hours for cold processes (10°C). Fouling, bacteria concentrations (or even growth) or/and compaction of boundary layer (e.g. protein gel layer or fat, which may alter separation characteristics) are limiting to run times.

Membrane Elements

Membranes are either made of polymers (organic) or ceramics (inorganic). The organic membranes are typically made as a spiral-wound element, and ceramic membranes are typically made as tubular elements.

Organic Membranes

Spiral-wound elements (SW) are most often used, since they are cheapest per square metre, compact, easy to replace and follow standardised dimensions. However, they are not suitable for liquids containing large number of suspended particles, which may be trapped inside the element construction (spacer net), or very viscous products.
The elements are 3.8" (4"), 6.3" (6") or 8.0" (8") in diameter and the length is 38" or 40". An element designated with the term "3840" means 3.8" diameter and 40" long. The elements can also be divided according to the height of the spacer net, which is designated in "mil" (1/1000 of an inch). If the viscosity of the liquid increases, which is happening during protein concentration, the spacer height
must be selected accordingly.

The following table summarises modules and their approximate membrane area:

Element type	4" (3840)	6" (6338)	8" (8040)
Membrane type	RO/NF/UF/MF	UF/MF	RO/NF
32 mil (0.8 mm)	7.4 m^2	20 m^2	32 m^2
48 mil (1.2 mm)	5.6 m^2	16 m^2	25 m^2
64 mil (1.6 mm)	4.6 m^2	13 m^2	20 m^2
80 mil (2.0 mm)	3.5 m^2	10 m^2	16 m^2
100 mil (2.5 mm)	-	8 m^2	-

SW loop configurations
SW elements are operated with a pressure drop of 0.8-1.2 bar per element (for 8" elements max. 0.6 bar). To avoid telescoping of the spiral, an *ATD* must be placed at the end and between the elements. SW elements can be mounted in series inside a *housing* (also called *pressure vessel* or *module*). Spacer height, flux curves, pump performances and pressure drops determine the configuration of a SW plant.

Plate & frame (P&F), module 37 (M37) is the only P&F module still in use and only for high viscosity products like cream

cheese (Philadelphia type). This module can go high in protein% (more than 29%), when operated with a positive pump up to 12 bar. The crossflow rate should be 25 l/plate/min.
When assembling new membranes, the module should be compressed applying 240kN (or 24 tons) of pressure (or until the module stops leaking!). The M37 module is increasingly challenged by newer module types, like specially designed SW elements and tubular ceramic membranes.

Inorganic Membranes (Ceramics)
Unlike the polymeric membranes (especially RO/NF), the ceramic material is very resistant to heat and chemicals, and ceramic membranes will last for typically 5-10 years or more. However, they are much more expensive, and generally require more pumping energy. Due to the ceramic nature, they are sensitive to mechanical vibrations (should always be installed vertically) and thermal shock.

Tubular membranes
APV's experience is largely based on the French "Exekia" membrane (formerly SCT). The membranes are tubular, with the feed circulating inside tubular channels. The diameter of these channels is 3, 4 and 6 mm, which is selected according to the viscosity of the product. The main application for ceramics is MF, since the ceramic element can be operated with permeate back-pressure, so as to achieve a low TMP, which is crucial for successful results. Two products are available: The standard element, where UTP operation is required (permeate recirculation to create permeate back-pressure) and the newer GP element, where the permeate back pressure/resistance is integrated inside the membrane structure (GP = Gradient Pressure).

Available MF pore sizes are: 0.1 – 0.2 – 0.5 – 0.8 – 1.4 – 2 – 3 – 5 microns, which are alumina membranes on alumina structure. UF pore sizes available are: 20 – 50 – 100 nm, which are zirconia material on alumina structure. For UF processes it is not necessary to control a low TMP.

Exekia Membralox membranes and their membrane areas:

Channel size Ø	3 mm (P37-30 GL)	4 mm (P19-40 GL)	6 mm (P19-60 GL)
1P housing (m^2)	0.35	0.24	0.36
3P housing (m^2)	1.05	0.72	1.08
7P housing (m^2)	2.45	1.68	Not available
12P housing (m^2)	Not available	Not available	4.32
19P housing (m^2)	6.65	4.56	7.92 (22P)

CIP

Cleaning of membranes is nothing like cleaning of standard dairy equipment made of stainless steel. Membrane elements are often organic polymeric membranes made of materials, which only tolerate certain cleaning limits in terms of pH and temperature (and desinfectants/oxidisers). Therefore it is almost always necessary to use formulated cleaning products including enzymatic products from approved suppliers like Henkel, Ecolab, DiverseyLever, Novadan and others. In the table below some limits are listed for different membrane materials.

Membrane material	Polyamide (RO/NF)	Polysulphone (UF)	Polysulphone (UF pHt)	Ceramic (MF/UF)
Support/backing	Polyester	Polyester	Polypropylene	Alumina
Max temp (°C)	50	50	70	85 (not critical)
Cooling rate	Not critical	Not critical	Not critical	Max 10°/min
PH range	1.5-11.5	1.5-11.5	1-13	1-14
Free chlorine	No	Max 200 ppm	Max 200 ppm	Not critical
Phosphoric acid	Yes	Yes	Yes	No
Surfactants	Only anionic	Only anionic	Only anionic	Not critical
Sanitation	0.2% bisulfite	0.2% bisulfite	0.2% bisulfite	0.5% nitric acid

Water flux: After installation and cleaning of new membranes, the water flux should be registered to be used for future reference. Organic membranes always stabilise within the first few weeks. Cleaning of membranes should always be followed by a water flux reading, which must be recorded at the same pressure, temperature, time and cleaning step, so the cleaning efficiency can be monitored.

CIP Water Quality Guidelines

For optimal cleaning and flushing of membranes, the water used should be within the following specifications.

Parameter	Units	RO/NF organic membrane	UF/MF organic membrane	UF/MF ceramic membrane
Iron (Fe)	mg/l	<0.05	<0.05	<0.1
Manganese (Mn)	mg/l	<0.02	<0.02	<0.05
Aluminium (Al)	mg/l	<0.05	<0.1	<0.1
Silica (SiO_2)	mg/l	<15	<15	<15
Chlorine (Cl_2/HOCl)	mg/l	<0.1	<5*	<5*
German Hardness	°dH	<15	<15	<15
Fouling Index	SDI	<3	<3	<3
Turbidity	NTU	<1	<1	<1
Total plate count 22°C Total plate count 37°C	per ml per ml	<1000 <10	<1000 <10	<1000 <10
Coliforms	per 100 ml	<1	<1	<1

*) The chlorine content should be max 5 mg/l in order to avoid development of chlorous gas when cleaning with acid.

The above-listed requirements are based upon the various requirements stated by our membrane manufacturers.
If the silica content is less than 5 mg/l, higher levels of iron (max. 0.2 mg/l) and manganese (max. 0.05 mg/l) may be accepted in some cases.
If water hardness is higher than 15°dH, it may still be accepted, but the CIP procedure will have to be modified accordingly (higher dosage concentrations, extra addition of EDTA/NTA, etc.)

Water source
Water classified as "Drinking Water" (potable) is generally acceptable, on the condition that the above-listed specifications are fulfilled. Softened water is also acceptable, but the conductivity should be min. 5 µS/cm, in order not to prolong flushing time resulting in unacceptably high water consumption.
RO permeate and evaporator condensate may contain some organic acids (COD > 20 mg/l). It should be stored at cold temperature and for as short time as possible before use. For intermediate flushing this water is fine. For final flushing there will be a risk of bacteria growth, when the plant is left closed down. This risk is reduced if the last cleaning step involves chlorine.
Some customers are adding antifoaming agents to their evaporator condensate. Antifoaming agents may block the membranes irreversibly and cannot be accepted in the water.

Notes on parameters

mg/l: In practice equal to ppm (parts per million)

*Silica: T*otal = colloidal + soluble silica. Silica is practically insoluble in water at any temperature and is very hard to remove from the membrane, especially once precipitated. Colloidal silica should be absent, or as low as possible.

Chlorine: Must be analysed on site as the chlorine quickly disappears from the sample

Hardness: Is determined from the content of calcium and magnesium (see formula for German hardness °dH).

$$°dH = 5.61 \times \left(\frac{ppmCa^{2+}}{40.1} + \frac{ppmMg^{2+}}{24.3}\right)$$

Total hardness = temporary + permanent hardness
Soft water < 8°dH medium water < 16°dH hard water.

1°dH equals 10 ppm CaO
or 7.14 ppm MgO
or 17.9 ppm $CaCO_3$
or 24.3 ppm $CaSO_4$
or 15.0 ppm $MgCO_3$

Equivalent units are listed below:

Unit	German °dH	Danish °dH	English °H	American °H	French °THF
1°dH German	1.00	1.00	1.25	17.85	1.79
1°dH Danish	1.00	1.00	1.25	17.85	1.79
1°H English	0.80	1.00	1.00	14.30	1.43
1°H American	0.056	0.056	0.07	1.00	0.10
1°THF French	0.56	0.56	0.70	10.00	1.00

Conductivity: If water is demineralised one should expect less than 30 µS/cm. In comparison, drinking water is in the range of 300-800 µS/cm.

Turbidity: Method: Particles scatter light (expressed in NTU, equal to JTU or FTU). Turbidity may also be expressed in SiO_2 (mg/l), where 10 mg/l equals 4 JTU.

Silt Density: Equal to Fouling Index, Colloid Index or Colmatation Index. This index is related to "Suspended Solids" and replaces this analysis.

Method: Pass the water through a 0.45 micron CA filter Ø 47 mm (ref. Milli-pore HAW PO 47000) at a constant pressure of 2.1 bar (30 psi). The time to pass 500 ml water is measured at

test start (t0) and 15 minutes (t15). SDI 0-3: Non-fouling, SDI 3-6: Some fouling, SDI 6-20: High fouling.

$$SDI = 100 \times \left(\frac{1-(t0/t15)}{15} \right)$$

CIP and hardness

The hardness of the water is an important factor, as it governs the dosage concentration of the cleaning chemicals and the flushing time. Soft water is the most gentle for the membranes, with a low risk of mineral precipitation on the membrane surface. However, soft water has a much reduced buffering effect when dosing cleaning chemicals, which means that pH limits are reached at lower concentrations. As a rule of thumb, if 2% may be tolerated in 20°dH before the pH limit is reached, only 1% may be tolerated in 10°dH (when applying Divos 124). However, these figures are not true for all caustic products, but the principle is the same. Lower concentrations reduce the cleaning efficiency even at the same pH, as there are less cleaning agents (surfactants, carriers, complexing agents) to bind or "carry" the soil and to keep it in solution until flushing. Severe foaming may also be a result of using soft water. The flushing time is prolonged with higher water consumption as a result (ever washed hands using soft water?). Some enzymatic products need certain minerals (e.g. calcium) in order to work. When using soft water, these minerals will have to be added. When using hard water extra complexing agents such as EDTA or NTA must be added in order to prevent mineral precipitation. The solubility of calcium salts is much reduced at higher temperatures resulting in heavy fouling of the membrane.

Pre-treatment methods

If some of the parameters do not meet the requirements, the following pre-treatments may be applied:

Cartridge filter: Reduces SDI and remove particles by raw water filtration (5-10 micron pore size).
Sand filter: Removes Fe and Mn.
Sand filter: Special filling material removes fouling particles (SDI/turbidity).
Active carbon: Removes organic matter and neutralises chlorine.
Bisulfite: Neutralises chlorine.
Ion exchange: Removes SiO_2, Al, Fe, Mn, softens hard water.
Chlorination: Kills bacteria (e.g. from surface water). One hour chlorination followed by dechlorination is recom-mended.

Milk and Whey Composition

Raw milk quality (Denmark, 2001):

	Extra	1st class	2nd class	3rd class
Total counts/ml	<30.000	30.000-100.000	100.000-300.000	>300.000
Somatic cells/ml	<300.000	300.000-400.000	400.000-650.000	>650.000
Anaerobic spores/l	<400	<400	400-1100	>1100
Freezing point °C	-0.543 to -0.516			
Antibiotics	Negative			

Composition of milk in Northern Europe (average values):

	Raw milk (DK/NL 1999)	Skim milk (Germany 2002)
FAT	4.3%	0.06%
TOP (total protein)	3.4%	3.63%
NPN (NPNx6.38)	0.19%	0.19%
TRP (true protein)	3.21%	3.44%
TWP (true whey proteins)	0.55%	0.60%
CAS (casein)	2.66%	2.84%
ACD (citric acid)	0.18%	0.20%
LAC (lactose)	4.65%	4.84%
TOA (total ash)	0.73%	0.77%
TS (total solids)	13.3%	9.50%
CAS/TRP ratio	83-84%	82.6%
CAS/TOP ratio	77-79%	78.2%
TWP/TOP ratio	16.5-15.5%	
NPN/TOP ratio	5.0-6.5%	5.2%

Components in milk and whey and their approximate size:

Large particles	**Diameter size in micron (my)**
Somatic cells (leukocytes)	10-20
Yeast cells	5-30
Bacteria cells	0.5-5
Bacteria spores (Bacillus/Clostridium)	0.8 x 1.5
Fat globules in raw milk	0.1-10 (2-6)
Fat globules in skim milk/homogenised milk	<1
Protein particles (colloidal)	**Diameter size in nanometer (nm)**
Lipoprotein particles (protein + P-lipids)	10
Casein micelle (app. 500 subunits) *(casein micelle = 70% water + 30% casein)*	10-300
Subunit of casein micelle (10 casein molecules)	10-12
Individual proteins	**Molecular Weight (MW = Daltons)**
Casein molecule	20-25.000
Para casein	12.200
Whey proteins (= serum proteins)	**3-6 nm**
Immunoglobulins (IgG)	150.000
Immunoglobulins (IgM)	900.000 (= 30 nm)
ß-lactoglobulin (ß-LG)	2 x 18.000
Alpha-lactalbumin	14.000
Bovin Serum Albumin (BSA)	66.000
Lactoferrin/Transferrin (LF)	77.000
Caseinomacropeptide (CMP/GMP)	6.800
Enzymes	
Lactoperoxidase (LP)	77.500
Cheese rennet (chymosin/rennin)	31.000
Xanthin Oxidase (XO) *(in fat globules)*	283.000
Milk Lipase (mLPL) *(in casein micelle)*	50.000
Phosphatase *(in fat globule membrane)*	2 x 85.000
Milk Plasmin *(in casein micelles)*	89.000

Components in milk and whey and their approximate size (continued):

Non-Protein Nitrogen (NPN)	**Molecular Weight (MW = daltons)**
Cholin (vitamin)	121
Amino acids	75-200
Peptides	200-1500
Urea-N	60
Creatin/creatinin	131
Carbohydrates/Acids	
Lactose	342
Glucose	180
Galactose	180
Lactulose	342
Lactic acid	90
Citric acid	192
Acetic acid	60
Minerals – positively charged	
Sodium (Na+)	23
Magnesium (Mg++)	24
Potassium (K+)	39
Calcium (Ca++) soluble	40
Minerals – negatively charged	
Chloride (Cl-)	35
Phosphate (PO4—) soluble	95
Sulphate (SO4—)	96
Carbonate (HCO3-)	61

Cleaning and Disinfecting

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

CIP Cleaning in General

Milk components are excellent substrates for microorganisms and a careful cleaning is thus very important. This does not alone apply to the parts in contact with the product, but also to the external parts and rooms etc.

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

1. *A chemical factor*
2. *A mechanical factor*
3. *A thermal factor*
4. *A time factor*

1. *The chemical factor* is determined by the cleaning agent and the concentration in which it is used.

   The cleaning agent is chosen according to the type of pollution to be removed, in this way:

Pollution	Basic	Acid
Fat	+	-
Protein	+	+
Ash (milk residues)	-	+
Water residues	-	+

   In the central CIP plant the majority of the cleaning solutions is led back to the CIP tanks and reused. Therefore, the concentration may be fixed at a suitable high level without too much waste.

The functions of the cleaning agents are:

- To loosen the pollution

- To keep the impurities dissolved in the cleaning solutions to prevent them from precipitation on the cleaned surfaces

- To prevent sedimentation of lactic salts.

Guiding concentrations: Acid (HNO_3) 0.8-1.2%, and lye (NaOH) 0.8-1.5%.

2. *The mechanical factor* is determined by the speed of the liquid over the surfaces. The faster the liquid moves, the more efficient the cleaning will be. It is important that the movement of the liquid is turbulent, i.e. that the liquid parts continuously change place mutually.

   Consequently, the pump speeds are considerably higher during CIP than during production.

   The cleaning turbines in the tanks make up an effective mechanical factory, but partial blockings of the turbines may appear. In consequence, the turbines should be inspected regularly.

3. *The thermal factor* (the temperature) is very important. Within chemistry it is said that the reaction speed is doubled if the temperature is increased by 10°C. However, a too high temperature also presents disadvantages, as residues of proteins and lactic salts are precipitated at too high temperatures, and the solubility of the salts in the water is reduced.

   Guiding temperatures: Lye solution 70 - 75°C and acid solution 60 - 65°C.

4. *The time factor* is important to the softening and solution part of the pollution.

   In the program survey, approximate periods for the single steps in the programs are indicated. The indicated periods should only be regarded as a broad guidance, as there may be considerable differences between the single routes, both as regards equipment to be cleaned and the fouling degree.

Disinfection
The purpose of a disinfection is to kill the largest possible number of bacteria to avoid an infection of the products. Heat in the form of steam or especially hot water is the most used form of disinfection. The central CIP plant includes programs for sterilisation with hot water, and the return temperature is set to 85 - 90°C.

Cleaning of dairy equipment is carried out as follows:

A. Pre-rinse
The processing equipment is rinsed with cold or warm water. The object is to remove any possible product residue before cleaning. The rinsing water containing the product residue should be led to suitable reception facilities in order to minimise pollution.

B. Cleaning with sodium hydroxide
The process equipment is cleaned by means of circulation of a hot sodium hydroxide cleaning solution. Today, special cleaning agents are commonly used instead of sodium hydroxide. After cleaning, the cleaning solution is collected and re-used. Re-use should not take place before the concentration of the returning solution (%) has been checked and adjusted accordingly.

C. Intermediate rinse
Any remaining cleaning solution is flushed out with either collected rinse water or fresh water.

D. Cleaning with nitric acid
The process equipment is cleaned by means of circulation of a hot nitric acid cleaning solution. Today, special cleaning agents are commonly used instead of nitric acid.
After cleaning, the cleaning solution is collected and re-used. Re-use should not take place before the concentration of the returning solution (%) has been checked and adjusted accordingly.

E. Final rinse
Any remaining cleaning solution is flushed out with either cold or hot water. Chemical free water is collected and used for pre-rinse.

F. Disinfection
This is carried out immediately before the product plant is put into operation. Disinfection can be carried out thermally or chemically. The CIP plant is normally designed to allow for disinfection by circulation of either hot water at 90-95°C or a solution of e.g. hydrogen peroxide. Today special agents for disinfection is widely used in place of hydrogen peroxide.
Disinfection must always be followed by a rinse with clean and drinkable water.

Cleaning Methods

Cleaning agents:
The following cleaning agents can be used for CIP-cleaning.

Lye, NaOH, Sodium hydroxide:
- 30% concentrated solution.

Acid, HNO3,Nitric acid:
- 30% concentrated solution.
- 62% concentrated solution.

Hydrochloric acid, (HCl), and/or chlorine-containing clea-ning agents, (Cl), must never be used.

Normally used cleaning solutions:

Lye:	NaOH - Solution for cleaning of tanks and pipes	0.8-1.2%
	Above corresponds to a titter of	20.0-30.0
Lye:	NaOH - Solution for cleaning of pasteuriser	1.2-1.5%
	Above corresponds to a titter of	30.0-37.5
Acid:	HNO3 - Solution for cleaning of tanks and pipes.	0.8-1.0%
	Above corresponds to a titter of	12.7-15.9
Acid:	HNO3 - Solution for cleaning of pasteuriser	0.8-1.2%
	Above corresponds to a titter of	12.7-19.0

Note: Titter corresponds to ml 0.1 N (NaOH or HCL), per 10 ml against phenolphthalein (8.4).

Reagents: 0.1 N Sodium hydroxide, (NaOH), solution.
0.1 N Hydrochloric acid, (HCl), solution.
5% Alcoholic phenolphthalein solution.

General maintenance of CIP plant:

Daily check: Control of lye and acid cleaning concentrations.

Weekly check: Control of stone deposits in lye tank/tanks and water tank/tanks.
Drawing off of bottom sludge from lye and acid tanks.

Monthly check: Control of various gaskets and replacement of these, if necessary.

Quarterly check: Change of cleaning solution in the lye and acid tanks.

CIP Cleaning Programs for Pipes and Tanks

Pipes	*Cleaning Time*
Picking up of residual products	* minutes
Pre-rinse, cold water/recyclable water	1-3 minutes
Lye cleaning 1% solution at 70°C (The time stated is only started when return concentration and return temperature are identical with the above)	6-10 minutes
Intermediate rinse, cold water/recyclable water - Special software solution	1-3 minutes
Acid cleaning 0.8% solution at 60°C (The time stated is only started when return concentration and return temperature are identical with the above)	4-6 minutes
Final rinse, cold water (The time stated is only started when return concentration indicates clean water)	1-3 minutes
Total cleaning time	** minutes

Hot water sterilisation at 85°C (The time stated is only started when return temperature is identical with the above)	3-5	minutes

Cold water disinfection with hydrogen peroxide, H_2O_2, solution 200 ppm.

*)
Time is dependent on the physical conditions in and around various pipes/pipelines to be cleaned.

**)
Time is dependent on the physical conditions in and around various pipes/pipelines to be cleaned as well as the software to control cleaning of pipes/pipelines.

Above times are stated as efficient cleaning times and should be seen as recommendable values. These values may change dependent on the physical conditions in and around various pipes/pipelines as well as the complexity of various products with regard to the physical/chemical conditions, as well as the complexity of various physical/chemical as well as microbiological deposits.

Tanks	*Cleaning Time*	
Picking up of residual products	*	minutes
Pre-rinse, cold water/recyclable water	1-3	minutes
Lye cleaning 1% solution at 70°C (The time stated is only started when return concentration and return temperature are identical with the above)	10-15	minutes
Intermediate rinse, cold water/recyclable water - special software solution	1-3	minutes
Acid cleaning 0.8% solution at 50-60°C (The time stated is only started when return concentration and return temperature are identical with the above)	4-6	minutes
Final rinse, cold water (The time stated is only started when return concentration indicates clean water)	0.5-1	minute

Total cleaning time	**	minutes
Hot water sterilisation at 85°C	3-5	minutes
(The time stated is only started when return temperature is identical with the above)		

Cold water disinfection with hydrogen peroxide, H_2O_2, solution 200 ppm

*)
Time is dependent on the physical conditions in and around various tanks to be cleaned (tank dimension).

**)
Time is dependent on the physical conditions in and around various tanks to be cleaned (tank dimension), as well as the software to control cleaning of tank/tanks.

Above times are stated as efficient cleaning times and should be seen as recommendable values. These values may change dependent on the physical conditions in and around various tanks (tank dimensions) as well as the complexity of various products with regard to the physical/chemical conditions, as well as the complexity of various physical/chemical as well as microbiological deposits.

CIP Cleaning Programs for Plate Pasteurisers

Pasteurisers	*Cleaning Time*	
Picking up of residual products	*	minutes
Pre-rinse, cold water/recyclable water	5-10	minutes
Lye cleaning 1.5% solution at 70°C (The time stated is only started when return concentration and return temperature are identical with the above)	45-60	minutes
Intermediate rinse, cold water/recyclable water - special software solution	5-10	minutes
Acid cleaning 0.8% solution at 50-60°C (The time stated is only started when return concentration and return temperature are identical with the above)	20-30	minutes

Final rinse, cold water (The time stated is only started when return concentration indicates clean water)	2-5	minutes
Total cleaning time	**	minutes
Hot water sterilisation at 85°C (The time stated is only started when return temperature is identical with the above)	15-20	minutes

Cold water disinfection with hydrogen peroxide, H_2O_2, solution 200 ppm.

*)
Time is dependent on the physical conditions in and around various pasteuriser/pasteuriser plants to be cleaned.

**)
Time is dependent on the physical conditions in and around various pasteuriser/pasteuriser plants to be cleaned as well as the software to control cleaning of pasteuriser/pasteuriser plants.

Above times are stated as efficient cleaning times and should be seen as recommendable values. These values may change dependent on the physical conditions in and around various pasteuriser/pasteuriser plants as well as the complexity of various products with regard to the physical/chemical conditions, as well as the complexity of various physical/chemical as well as microbiological deposits.

Pasteurisers	CIP*
Continuous buttermaking machines	CIP** special
Ultrafiltration plants (UF)	CIP*** special
Evaporators	CIP

*) As a consequence of both a higher detergent concentration and a longer cleaning period compared with the cleaning of pipes and tanks, it may be appropriate to clean the pasteurisation plant independently of the CIP plant for pipes and milk tanks.
At the end of the production run, the pasteurisers, including pumps, valves and pipes, are flushed out with cold

water until the water is clear and free of milk at the outlet. A closed circulating flow is then established by leading the water from the outlet back to the balance tank and slowly adding approx. 3.5-4.0 l 30% sodium hydroxide (NaOH) per 100 kg water in the system. If the sodium hydroxide is in dry form, it should be dissolved in approx. 10 l cold water per kg NaOH before it is added to the balance tank. *Warning:* NaOH should always be mixed slowly into cold water - never water into NaOH as it will boil up with explosive force. Always use facial protection when working with concentrated detergents. If the volume of the plant is unknown, the concentration must be checked as described below.

If the water is very hard, 300-500 g trisodium phosphate should also be added.

The temperature is raised to 70-75°C and circulation is continued for at least 45-60 minutes.

The NaOH solution is flushed out with water and the circulating flow is re-established. Then, approx. 2.5 l nitric acid (30%) is added slowly and circulated for 20-30 minutes at 60-65°C after which the acid is flushed out with water.

Before start-up of the next production run, the pasteurisation system is disinfected by circulation of hot water at 90°C for 15-20 minutes. Cooling and pasteurising temperatures are adjusted to normal production before the water is forced out with milk.

**) CIP of buttermaking machines is always carried out without the use of the ordinary CIP plant, because relatively large amounts of fat residue must be removed by the detergent and because the cleaning of buttermaking equipment must give the machine surfaces a protective coating, which serves to prevent the butter from adhering to the surfaces. For cleaning, an internal circulating flow is established.

***) CIP of a UF plant is always carried out by means of an internal circulating flow as special detergents are used in order to prevent any damage to the membranes, which would reduce the permeate flow.

General Comments to Defects/Faults in CIP Cleaning

In case of unsatisfactory cleaning, the following defects/faults may be the cause:

1. CIP flow speed too low
2. Cleaning time too short

3. Cleaning concentration (lye or/and acid) too low
4. Cleaning temperature too high/low
5. Time of production without cleaning too long
6. Etc.

Manual Cleaning

CIP is automatic cleaning, but firstly the external surfaces are not cleaned by CIP, secondly there will always be a few machine parts that have to be cleaned every day. Futhermore, requirements for disassembling of large machine parts, a.o. plate heat exchangers and pipe connections, will arise at intervals.

Dirty surfaces, e.g. due to leakage, must be cleaned every day with hot soapy water and rinsed with clean water.

Cleaning also includes the rooms, and plans for regular manual cleaning of both rooms and equipment should be worked out.

A visual control of the effectiveness of the cleaning may be difficult. Although a surface seems clean, there may be a large number of bacteria per cm^2.

Check of the Cleaning Effect

Hygienic control

Apart from the daily visual control with the hygienic condition of the production equipment and the production rooms, microbiological examinations should be made for determination of the state of cleaning effect, for instance by means of the swabbing method.

Equipment:

1. Swabs made of cotton wool coiled around the end of a small stick.

2. Test tubes with 10 ml Ringer's liquid.

3. Ordinary equipment for bacteriological examinations.

Procedure:

1. The swab is sterilised in the test tube with Ringer's liquid.

2. Approx. 100 cm^2 (10 x 10 cm) of the surface to be examined are rubbed with the swab.

3. The swab is transferred to the test tube (1) again, and the upper part of the stick, which has been touched, is broken off.

4. Dependent on the degree of pollution, 1 ml or 0.1 ml, maybe 0.01 ml is transferred to a sterile Petri dish, and substrate is poured on according to the type of bacteria to be examined.

After incubation, the state of the cleaning effect is judged after the following scale:

Number of total bacteria per 100 cm^2 surface	State of cleaning effect
0-10	Very good
10-100	Good
over 100	Bad

Control of the cleaning liquids and temperature
Naturally, it is important to keep the right strength in the cleaning agents and the right temperature.

The mentioned guiding figures may be summarised here:

	Concentration	Temperature
Hot water		85 - 90°C
Concentrated acid	30 or 60 - 62%	Room temperature
Concentrated lye	30-33%	Room temperature
Acid cleaning solution	0.8 - 1.2%	60 – 65°C
Lye cleaning solution	0.8 - 1.5%	70 – 75°C

Control of the strength of the cleaning agents should be made twice a day.

Emptying of the tanks will be necessary at intervals depending on fouling and may take place by opening the bottom valves manually.

Control of Cleaning Solutions

Determination of the strength of lye by titration
In order to obtain a satisfactory cleaning effect it is important that during the whole course of cleaning the lye solution keeps the right strength according to the directions for use.

Equipment:
1. Titration burette (25 ml)

2. 10 ml pipette or measuring glass

3. Drop bottle

4. Phenolphthalein solution (2%)

5. Titration flask 100 ml

6. 0.1 N hydrochloric acid.

Method:

1. Hot cleaning solution is removed from the lye tank with a ladle, and the solution is cooled to approximately 20°C.

2. 10 ml lye solution is measured with a measuring glass or a pipette, and this solution is transferred to a flask.

3. Five drops of phenolphtalein solution are added, by which the lye solution is coloured red.

4. Under careful shaking this is titrated with 0.1 ml normal hydrochloric acid until the colour changes. The colour changes from red to colourless.

5. Number of ml consumed of 0.1 normal acid is read on the burette and corresponds to the titer of the lye solution.

The titer of the lye solution corresponds to the concentration of the cleaning solution.
The concentration in the cleaning solution can be calculated as follows:

$$\text{Concentration in \%:} \quad \frac{a \times b \times c}{100} = xx.x\ \%$$

Where:
a = ml titration fluid until colour change/10 ml solution

b = normality of titration fluid (0.1)

c = molecular weight (NaOH = 40.0)

Example:

$$\text{Concentration in \%} \quad \frac{25.0 \times 0.1 \times 40.0}{100} = 1.00\ \%$$

Determination of the strength of the acid by titration
Acid cleaning solutions containing nitric acid (technically clean, approximately 62%) are used at the dairies with mechanical cleaning of pipes and tanks of completely stainless

material. Acid solutions dissolve calcium oxide coatings, and lye solutions dissolve protein coatings. This is why combined cleaning is used, e.g. lye solution at first, then acid solution, or in reverse order, depending on which cleaning technique gives the best result on the spot.

Equipment:
1. Titration equipment (see under lye solution).

2. 0.1 N sodium hydroxide.

Method:
1. The acid solution is removed from the acid container, and this solution is cooled to approximately 20°C.

2. 10 ml acid solution is measured with a measuring glass or a pipette, and this solution is transferred to a titration flask.

3. Five drops of phenolphtalein solution are added.

4. Under careful shaking this is titrated with 0.1 normal sodium hydroxide until the colour changes. The colour changes from colourless to red.

5. Number of ml consumed of 0.1 normal lye is read on the burette and corresponds to the titer of the acid solution.

The titer of the acid solution corresponds to the concentration of the cleaning solution.

The concentration in the cleaning solution can be calculated as follows:

Concentration in %: $\frac{a \times b \times c}{100} = xx.x\ \%$

Where:

a = ml titration fluid until colour change/10 ml solution

b = normality of titration fluid (0.1)

c = molecular weight (HNO_3 = 63.02)

Example:

Concentration in % $\frac{15.9 \times 0.1 \times 63.02}{100} = 1.00\ \%$

In order to make the calculation easier it is possible to work out tables for the lye or acid strength and titer, e.g. from 0.1%-2% so that it is possible to read the lye or acid strength directly. (see Table: Concentration of Cleaning Solution)

To compare the strength of the cleaning solution and the conductivity measured in milli-siemens mS please look in the manual of Henkel P3-LMIT 08.

Concentration of Cleaning Solution

Lye NaOH Sodium Hydroxide		Concentration	Acid HNO_3 Nitric acid		
Titration 0.1 n HCL ml/10 ml	30% NaOH l/100 l	%	30% HNO3 l/100 l	62% HNO3 l/100 l	Titration 0.1 nNaOH ml/10 ml
2.5	0.25	0.1	0.30	0.10	1.60
5.0	0.50	0.2	0.55	0.25	3.20
7.5	0.75	0.3	0.85	0.35	4.80
10.0	1.00	0.4	1.15	0.45	6.30
12.5	1.25	0.5	1.40	0.60	7.90
15.0	1.50	0.6	1.70	0.70	9.50
17.5	1.75	0.7	2.00	0.80	11.10
20.0	2.00	0.8	2.25	0.95	12.70
22.5	2.25	0.9	2.55	1.05	14.30
25.0	2.50	1.0	2.80	1.15	15.90
27.5	2.75	1.1	3.10	1.30	17.50
30.0	3.00	1.2	3.40	1.40	19.00
32.5	3.25	1.3	3.65	1.50	20.60
35.0	3.50	1.4	3.95	1.65	22.20
37.5	3.75	1.5	4.25	1.75	23.80
40.0	4.00	1.6	4.50	1.85	25.40
42.5	4.25	1.7	4.80	2.00	27.00
45.0	4.50	1.8	5.10	2.10	28.60
47.5	4.75	1.9	5.35	2.20	30.10
50.0	5.00	2.0	5.65	2.35	31.70

Dairy Effluent

Increasing discharge costs make it important to have knowledge of both the quantity of effluent and the content of pollutants. The pollutants in dairy effluent are primarily the organic substances fat, protein, and lactose, but nitrate and phosphate are also important substances.

Two methods are used to determine the content of organic material in effluent: BOD and COD. The result is expressed in mg oxygen per litre.
BOD (Biological Oxygen Demand) is determined by the demand of dissolved oxygen for oxydising the organic material in an aqueous sample of the effluent in 5 days at 20°C.
COD (Chemical Oxygen Demand) is determined by treating a sample with a potassium dichromate solution and neutralising excess dichromate by titration with ferrous ammonium sulphate.
It is not possible to convert BOD directly to COD as the values for the two methods are dependent on the varying composition of the organic matter. For dairy effluent the following conversion can be used as a guideline:
1 mg BOD = 1.3-1.5 mg COD
1 mg COD = 0.75-0.67 mg BOD

The table below lists COD values and thus the "pollution degree" of whole milk, skimmilk, and whey:

Substance	Whole milk		Skimmilk		Whey	
	Content mg/l	mg COD/kg	Content mg/l	mg COD/kg	Content mg/l	mg COD/kg
Fat	40,000	120,000	400	1,200	400	1,200
Protein	34,000	46,000	34,000	46,240	10,000	13,600
Lactose	46,000	52,000	47,000	53,110	47,000	53,110
Total, approx.		220,000		100,000		70,000

A term often used to describe the "pollution degree" is "person equivalent" (p.e.). One p.e. corresponds to 250 l of water polluted to a COD value of 600. In other words, 1 p.e. corresponds to 250 x 600 = 150,000 mg COD.

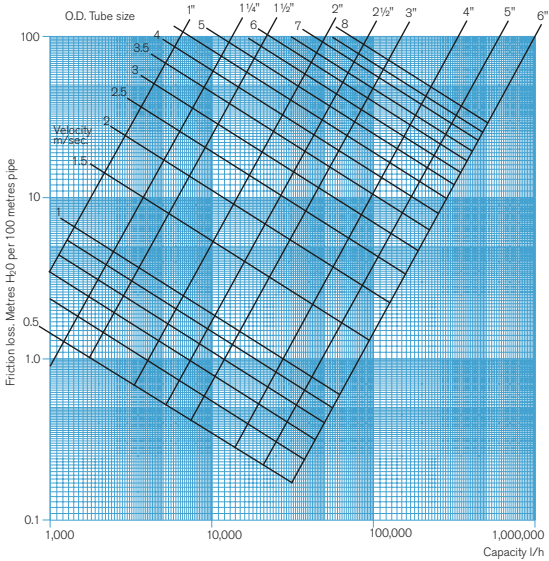
Example:
A dairy receives a daily quantity of 300,000 litres of milk. The loss is estimated to be 1%, ie, 3,000 l/day.

$$\text{COD: } \frac{3{,}000 \times 218}{150{,}000} = 4{,}360 \text{ p.e.}$$

Or, in other words, effluent pollution equal to the pollution from 4,360 people.

Stainless Steel Pipes

Capacity, friction loss and velocity of flow



Example:
10,000 l/h in a 2" stainless steel pipe.
Velocity: 1.5 m/sec.
Friction loss: 5.5 m H_2O per 100 m pipe.

When pipe dimensions are determined, the water velocity must not exceed 3 m/sec in small pipeline dimensions up to about 3". However, in bigger pipeline dimensions. a velocity of up to 3.5 m/sec. might be accepted.

In milk lines, especially for unpasteurised milk, with pipe dimensions below 3", the velocity should not exceed 1.5 m/sec. in the suction line and 2 m/sec. in the pressure lines. As concerns pipe dimensions of 3" and 4", a velocity of up to 2 and 2.5 m/sec. is acceptable, and for pipe dimensions 5" and 6" or bigger even higher velocities can be accepted

In pipelines for cream (40% fat) and other viscous dairy products, the velocity should be kept at a lower level. For special products like fermented milk products, the velocity should be kept at only 25-40% of the levels for milk.

Friction Loss Equivalent in m Straight Stainless Steel Pipe for One Fitting

Nominal diam. / Fitting	25 mm	38 mm	51 mm	63.5 mm	76 mm	101.6 mm
Valve (two-way)	6	8	8	9	10	10
Valve (three-way)	7	9	9	10	12	12
Elbow	0.8	1	1	1	1.5	1.5
Tee	2	3	3	4	5	5

The figures for pressure loss taken from the diagram are fairly good approximations for liquids having viscosities below 5 cPs, such as water, whole milk and skimmilk.

Velocity in Stainless Steel Pipes

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

Product	Suction lines		Pressure lines	
	25 mm ø	101.6 mm ø	25 mm ø	101.6 mm ø
Milk	1.5	2.0	2.0	2.5
Cream	1.5	1.5	2.0	2.0
Water	3.0	3.0	3.0	3.5

For CIP cleaning, the velocity should not be less than 1.5 m/sec.

Volume in Stainless Steel Pipes

Outside diameter	Inside diameter	Litre/metre
25.0 mm	22.6 mm	0.4011
38.0 mm	35.6 mm	0.9954
51.0 mm	48.6 mm	1.8551
63.5 mm	60.3 mm	2.8558
76.0 mm	72.9 mm	4.1739
101.6 mm	97.6 mm	7.4815
129.0 mm	125.0 mm	12.2718
154.0 mm	150.0 mm	17.6715

Friction Loss in m H_2O per 100 m Straight Pipe with Different Pipe Dimensions and Capacities (Non-stainless steel)

Small figures: Velocity in metres per second.

Large figures: Loss of head in m H_2O per 100 m pipe.

A: Friction loss in 90°C elbow or sluice valve indicated in metres of straight pipe.

B: Friction loss in Tee or non-return valve indicated in metres of straight pipe. (For foot, valves, multiply by 2).

Friction loss: $\frac{\text{pipe length in metres}}{100}$ x figures from table (metre head)

Quantity of water			Nominal diameter in inches and inside diameter in mm												
m³/h	l/min.	l/sec.	½" 15.75	¾" 21.25	1" 27.0	1¼" 35.75	1½" 41.25	2" 52.50	2½" 68.00	3" 80.25	3½" 92.50	4" 105.0	5" 130.0	6" 155.5
0.6	10	0.16	0.955 9.910	0.470 2.407	0.292 0.784									
0.9	15	0.25	1.282 20.11	0.705 4.862	0.438 1.570	0.249 0.416								
1.2	20	0.33	1.710 33.53	0.940 8.035	0.584 2.588	0.331 0.677	0.249 0.346							
1.5	25	0.42	2.138 49.93	1.174 11.91	0.730 3.834	0.415 1.004	0.312 0.510							
1.8	30	0.50	2.565 69.34	1.409 16.50	0.876 5.277	0.498 1.379	0.347 0.700	0.231 0.223						
2.1	35	0.58	2.993 91.54	1.644 21.75	1.022 6.949	0.581 1.811	0.436 0.914	0.269 0.291						
2.4	40	0.67		1.879 27.66	1.168 8.820	0.664 2.290	0.449 1.160	0.308 0.368						
3.0	50	0.83		2.349 41.40	1.460 13.14	0.830 3.408	0.623 1.719	0.385 0.544	0.229 0.159					
3.6	60	1.00		2.819 57.74	1.751 18.28	0.996 4.718	0.748 2.375	0.462 0.751	0.275 0.218					
4.2	70	1.12		3.288 76.49	2.043 24.18	1.162 6.231	0.873 3.132	0.539 0.988	0.321 0.287	0.231 0.131				
4.8	80	1.33			2.335 30.97	1.328 7.940	0.997 3.988	0.616 1.254	0.367 0.363	0.263 0.164				
5.4	90	1.50			2.627 38.30	1.494 9.808	1.122 4.927	0.693 1.551	0.413 0.449	0.296 0.203				
6.0	100	1.67			2.919 46.49	1.660 11.90	1.247 5.972	0.770 1.875	0.459 0.542	0.329 0.244	0.248 0.124			
7.5	125	2.08			3.649 70.41	2.075 17.93	1.558 8.967	0.962 2.802	0.574 0.809	0.412 0.365	0.310 0.185	0.241 0.101		
9.0	150	2.50				2.490 25.11	1.870 12.53	1.154 3.903	0.688 1.124	0.494 0.506	0.372 0.256	0.289 0.140		
10.5	175	2.92				2.904 33.32	2.182 16.66	1.347 5.179	0.803 1.498	0.576 0.670	0.434 0.338	0.337 0.184		
12	200	3.33				3.319 42.75	2.493 21.36	1.539 6.624	0.918 1.901	0.659 0.855	0.496 0.431	0.385 0.234	0.251 0.084	

15	250	4.17				4.149 64.86	3.117 32.32	1.924 10.03	1.147 2.860	0.823 1.282	0.620 0.646	0.481 0.350	0.314 0.126	
18	300	5.00					3.740 45.52	2.309 14.04	1.377 4.009	0.968 1.792	0.744 0.903	0.577 0.488	0.377 0.175	0.263 0.074
24	400	6.67					4.987 78.17	3.078 24.04	1.836 6.828	1.317 3.053	0.992 1.530	0.770 0.829	0.502 0.294	0.351 0.124
30	500	8.83						3.848 36.71	2.295 10.40	1.647 4.622	1.240 2.315	0.962 1.254	0.628 0.445	0.439 0.187
36	600	10.0						4.618 51.84	2.753 14.62	1.976 6.505	1.488 3.261	1.155 1.757	0.753 0.623	0.526 0.260
42	700	11.7							3.212 19.52	2.306 8.693	1.736 4.356	1.347 2.345	0.879 0.831	0.614 0.347
48	800	13.3							3.671 25.20	2.635 11.18	1.984 5.582	1.540 3.009	1.005 1.066	0.702 0.445
54	900	15.0							4.130 31.51	2.965 13.97	2.232 6.983	1.732 3.762	1.130 1.328	0.790 0.555
60	1000	16.7							4.589 38.43	3.294 17.06	2.480 8.521	1.925 4.595	1.256 1.616	0.877 0.674
75	1250	20.8								4.117 26.10	3.100 13.00	2.406 7.010	1.570 2.458	1.097 1.027
90	1500	25.0								4.941 36.97	3.720 18.42	2.887 9.892	1.883 3.468	1.316 1.444
105	1750	29.2									4.340 24.76	3.368 13.30	2.197 4.665	1.535 1.934
120	2000	33.3									4.960 31.94	3.850 17.16	2.511 6.995	1.754 2.496
150	2500	41.7										4.812 26.26	3.139 9.216	2.193 3.807
180	3000	50.0											3.767 13.05	2.632 5.417
240	4000	66.7											5.023 22.72	3.509 8.926
300	5000	83.3												4.386 14.42
A			1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.7	2.0	2.5
B			4.0	4.0	4.0	5.0	5.0	5.0	6.0	6.0	6.0	7.0	8.0	9.0

Units of Measure

The MKSA System

The unit of weight is one kilogramme (kg).

The unit of force is one kilogramme-force (kgf).
In certain countries the designation kilopond (kp) is used. 1 kp = 1 kgf.
The unit of length is one metre (m).

The unit of time is one second (s).

The unit of temperature is one degree Celsius (IC).

The terminal unit is one kilocalorie (kcal).
One kilocalorie (kcal) is equal to the amount of heat required to heat or cool 1 kg water one degree Celsius.

The specific gravity (density) is equal to the weight in grammes (g) of one cubic centimetre (cm^3) of a substance.

The unit of work, one kilogramme-force metre (kgfm) is equal to the energy required to raise one kilogramme to a height of one metre.

The unit of effect, one horse power (hp), is equal to a work performance of 75 kilogramme-force metres per second (kgfm/s).

One horse power hour (hph) is equal to the work that can be carried out by one horse power (hp) in one hour.

Specific heat is equal to the number of kilocalories required to heat 1 kg of a substance 1°C.

Example:	water	1
	iron	0.114
	copper	0.09
	air	0.24

The latent heat of fusion is equal to the number of kilocalories required to change I kg of solid substance to liquid when it has previously been heated to melting point.

Example:	ice	80

The thermal conductivity coefficient is equal to the number of kilocalories that are transmitted in one hour through a 1 m^2 cross section of a 1 m thick plate when the temperature difference is 1°C.

The latent heat of evaporation is equal to the number of kilocalories necessary to change 1 kg of liquid to vapour of the same temperature.

Example: water at 0°C: 607
water at 100°C: 536

The degree of humidity, relative humidity, is equal to the relation between the actual water vapour content of the air, and the amount of water vapour the air can hold at the temperature in question.

The absolute humidity is equal to the weight in grammes of the water vapour contained in 1 cubic metre of air.

The dew point is equal to the temperature reached when air is cooled to saturation point.

A technical atmosphere, 1 at, is equal to a pressure of:
(1) 1 kgf per cm^2
(2) a 10 m column of water (H_2O) at 0°C, or
(3) 73.6 em mercury (Hg).
1 ata is absolute pressure,
1 ato is the pressure above atmospheric pressure (i.e. 1 ato = 2 bar).

A normal atmosphere, 1 atm, is equal to a pressure of:
(1) 1.033 kgf/cm^2
(2) 1013 millibars of 76.0 cm mercury (Hg).

The unit current intensity, one ampere (A), is equal to a current which, when passed through a solution of nitrate of silver, is capable of depositing silver at the rate of 1.118 milligrammes per second.

The unit of resistance, one ohm (Ω), is equal to the resistance in a column of mercury, 106.3 cm long and with a cross section of 1 mm^2, at a temperature of 0°C.

The unit of potential, one volt (V), is equal to the difference in electrical potential between two separate points on a conduc-

tor with a resistance of 1 ohm, and where the electric current is one ampere.

The unit of power, one watt (W), is equal to the energy produced when the strength of the electric current is I ampere and the potential difference 1 volt.

The unit of electric energy, one kilowatt hour (kWh) is equal to the energy that is (produced or used) by 1 kilowatt (kW) working for 1 hour (h).

Conversion Table
Power, heat flow rate

	hp	kgfm/s	IW	kcal/h
hp*)	1	75	736	632
kgfm/s	1.33×10^{-2}	1	9.81	8.43
W	1.36×10^{-3}	0.102	1	0.860
kcal/h	1.58×10^{-3}	0.119	1.16	1

Energy, work, quantity of heat

	hph	kgfm	kWh	kcal
hph	1	2.70×10^{-5}	0.736	632
kgfm	3.75×10^{-6}	1	2.75×10^{-6}	2.34×10^{-3}
kWh	1.36	0.367×10^{-6}	1	860
kcal	1.58×10^{-3}	427	1.16×10^{-3}	1

* metric

The SI Unit System

SI (Système International d'Unités) is a metric system of international units which lends itself to simplification and systemisation. The SI system is gaining popularity throughout the world and forms the basis of the first truly international system of measurement. Such units as metre, kilogramme, litre, etc, will eventually be used world-wide. There is a definite advantage in applying the same units for all sizes, irrespective of the area measured. For example, the unit of power (Watt) can be used for electric motors and combustion engines. Horsepower will gradually disappear from the language. Thanks to uniformity and systemisation, no conversion factors will be required under the SI unit system.
SI includes a range of basic units, derivatives, multiples and sub-multiples. There are also supplementary units, primarily associated with subdivision of the 24-hour day.

Basic SI units:

Length	(m) metre
Mass	(k) kilogram
Time	(s) second
Electric current	(A) ampere
Thermodynamic temperature	(K) kelvin
Luminous intensity	(cd) candela
Amount of substance	(mol) mole

Supplementary units:

Plane angle	(rad) radian
Solid angle	(sr) steradian

The table below can be used to convert MKSA units used in this booklet and other common units to SI units.

Force	newton	N	$kg \times m/s^2$
Work Energy Quantity of heat	joule	J	$kg \times m^2/s^2 = N \times m = W \times s$
Power	watt	W	$kg \times m^2/s^3 = J/s$
Pressure	pascal	Pa	N/m^2
	bar	bar	10^5 Pa

Tables showing conversion Factors between SI Units and other Common Unit Systems.

Example showing use of pressure/stress table:
1450 p.s.i. converted to bar?
Find factor for bar, line p.s.i. = 1
$6.9 \times 10^{-2} \times 1450 \sim 100$ bar

Length

SI unit m	Other units			
	in (inch)	ft (foot)	yd (yard)	mile
1	39.4	3.28	1.09	0.621×10^{-3}
2.54×10^{-2}	1	8.33×10^{-2}	2.77×10^{-2}	15.8×10^{-6}
0.305	12	1	0.333	0.189×10^{-3}
0.914	36	3	1	0.568×10^{-3}
1.161×10^{3}	63.4×10^{3}	5.28×10^{3}	1.76×10^{3}	1

Area

SI unit m^2	Other units			
	in^2 (square inch)	ft^2 (square foot)	yd^2 (square yard)	
1	1.55×10^{3}	10.8	1.20	
0.645×10^{-3}	1	6.94×10^{-3}	0.772×10^{-3}	
9.29×10^{-2}	144	1	0.111	
0.836	1.30×10^{3}	9	1	

Volume

SI unit m^3	Other units				
	in^3 (cubic inch)	ft^3 (cubic foot)	yd^3 (cubic yard)	gallon (UK)	gallon (US)
1	61.0×10^3	35.3	1.31	220	264
16.4×10^{-6}	1	0.579×10^{-3}	0.214×10^{-6}	3.60×10^{-3}	4.33×10^{-3}
2.83×10^{-2}	1.73×10^3	1	3.70×10^{-2}	6.23	7.48
0.765	46.7×10^3	27	1	168	202
4.55×10^{-3}	277	0.161	5.95×10^{-3}	1	1.20
3.79×10^{-3}	231	0.134	4.95×10^{-3}	0.833	1

Velocity

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

Mass

SI unit kg	Other units	
	metric tech. unit of mass	lb (pound)
1	0.102	2.21
9.81	1	21.7
0.454	4.63×10^{-2}	1

Force, weight

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

Moment of force

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

Pressure, stress

SI unit N/m^2 Pa (pascal)	Other units				
	bar	kp/cm^2, at (tech. atmosph.)	mmH_2O	mmHg torr	lbf/in^2 p.s.i.
1	10^{-5}	10.2×10^{-6}	0.102	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), 1 atm = 101325 N/m^2

Energy, work, quantity of heat

SI unit J, Nm, Ws	Other units				
	kWh	kpm	kcal	Btu (Brit. thermal unit)	ft x lbf (foot pound-force)
1	0.278×10^{-6}	0.102	0.239×10^{-3}	0.948×10^{-3}	0.738
3.6×10^6	1	0.367×10^6	860	3.41×10^3	2.66×10^6
9.81	2.72×10^{-6}	1	2.34×10^{-3}	929×10^{-3}	7.23
4.19×10^3	1.16×10^{-3}	427	1	3.97	3.09×10^3
1.06×10^3	0.293×10^{-3}	108	0.252	1	779
1.36	0.377×10^{-6}	0.138	0.324×10^{-3}	1.29×10^{-3}	1

Power, heat flow rate

SI unit W, Nm/s, J/s	Other units				
	kpm/s	kcal/h	Btu/h	hp (Brit. horsepower)	hK (metr. horsepower)
1	0.102	0.860	3.41	1.34×10^{-3}	1.36×10^{-3}
9.81	1	8.43	33.5	1.32×10^{-2}	1.33×10^{-2}
1.16	0.119	1	3.97	1.56×10^{-3}	1.58×10^{-3}
0.293	2.99×10^{-2}	0.252	1	0.393×10^{-3}	0.399×10^{-3}
746	76.0	641	2.55×10^{3}	1	1.01
7.36	75	632	2.51×10^{3}	0.986	1

Input and Output of Electric Motors

	Alternating current	
	1 phase	3 phases
Current input (kW) =	$\frac{U \times I \times \cos}{1000}$	$\frac{3 \times U \times I \times \cos}{1000}$
Mechanical output (hp)	$\frac{U \times I \times \cos}{736}$	$\frac{3 \times U \times I \times \cos}{736}$

U = Voltage; for thre-phase networks,
U represents tension between two phases
I = Amperage
cos φ: See table below
n: See table below
$\sqrt{3} = 1.73$

kW, hp and Full-load Current for 3x380 Volt, 50 Cycle Electric Motors, and Approximate Values of cos φ and n (at 1500 rpm)

kW	hp	Full-load current amp.	cos φ	n
0.37	0.5	1.0	0.73	70.5
0.55	0.75	1.45	0.75	71.0
0.75	1.0	1.85	0.78	72.0
1.1	1.5	2.6	0.82	77.0
1.5	2.0	3.4	0.83	78.0
2.2	3.0	4.9	0.83	78.0
3.0	4.0	6.3	0.84	79.0
3.7	5.0	7.8	0.84	80.0
4.0	5.5	9.0	0.84	82.0
5.5	7.5	11.5	0.84	84.0
7.5	10.0	15.0	0.85	86.0
11.0	15.0	22.0	0.86	87.0
15.0	20.0	29.0	0.86	88.0
18.5	25.0	36.0	0.87	89.0
22.0	30.0	42.0	0.88	90.0
30.0	40.0	56.0	0.90	91.0
37.0	50.0	69.0	0.86	92.0
45.0	60.0	83.0	0.87	92.0
55.0	75.0	104.0	0.87	92.0
75.0	100.0	136.0	0.87	92.0

Fuel Table

Fuel	Calorific value kcal. kg	Price per ton DKK	Thermal efficiency in boiler %	Effective kcal.	Price per 1000 effective kcal. Øre	kg steam per kg fuel (7 atm. abs.)	Price per kg steam Øre
Light fuel oil	9850	3380	75	7390	14.89	11.20	9.82
Heavy fuel oil (1500 sec.)*	9775	2635	72	7040	9.59	10.66	6.33
Heavy fuel oil (3500 sec.)	9750	2513	70	6825	9.52	10.34	6.29
Steam coal	7000	1675	62	4340	12.10	6.25	7.99
Singles, Stoker	6800	1475	69	4690	10.34	7.11	6.82
Screened coal	6500	1140	55	3575	10.77	5.42	7.10

**) The viscosity measured in Redwood seconds at 100°F.*

1 kg steam at a pressure of 7 atm. abs. = 659.4 ~ 660 kcal.

In the part of the table dealing with oil-firing, the expenses of atomising the oil have not been considered.

Saturated Steam Table

(according to Mollier)

Absolute pressure Atmos.	Temperature °C	Enthalpy kg°	Absolute pressure Atmos.	Temperature °C	Enthalpy kg°
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	151.11	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

Atomic Weights, Melting and Boling Points of the Elements

Name	*Sym-bol*	*Atomic number*	*Atomic weight*	*Foot-notes*	*Melting point (°C)*	*Boiling point (°C)*
Actinium	Ac	89	227.028	L	1050	3200±300
Aluminium	Al	13	26.9815		660.37	2467
Americium	Am	95	(243)		994±4	2607
Antimony (Stibium)	Sb	51	121.75		630.74	1750
Argon	Ar	18	39.948	g, r	- 189.2	- 185.7
Arsenic	As	33	74.9216		817 (28 alm)	613 (sub)
Astatine	At	85	(210)		302	337
Barium	Ba	56	137.33	g	725	1640
Berkelium	Bk	97	(247)			
Beryllium	Be	4	9.01218		1278±5	2970 (5 mm)
Bismuth	Bi	83	208.980		271.3	1560±5
Boron	B	5	10.81	m, r	2079	2550 (sub)
Bromine	Br	35	79.904		- 7.2	58.78
Cadmium	Cd	48	112.41	g	320.9	765
Caesium (Cesium)	Cs	55	132.905		2840±0.01	669.3
Calcium	Ca	20	40.08	g	839±2	1484
Californium	Cf	98	(251)			
Carbon	C	6	12.011	r, t	3652 (sub)	1
Cerium	Ce	58	140.12	g	798	3443
Cesium (Caesium)	Cs	55	132.9054		2840±0.01	669.3
Chlorine	Cl	17	35.453		- 100.98	- 34.6
Chromium	Cr	24	51.996		1857±20	2572
Cobalt	Co	27	58.9332		1495	2870
Copper (Cuprum)	Cu	29	63.546	r	1083.4±0.2	2567
Curium	Cm	96	(247)		1340±40	
Dysprosium	Dy	66	162.50		1412	2567
Einstenium	Es	99	(252)			
Erbium	Er	68	167.26		1529	2868
Europium	Eu	63	151.96	g	822	1527
Fermium	Fm	100	(257)			
Fluorine	F	9	18.9984		- 219.62	- 188.14
Francium	Fr	87	(223)		(27)	(677)
Gadolinium	Gd	64	157.25	g	1313	3273
Gallium	Ga	31	69.72		29.78	2403
Germanium	Ge	32	72.59		937.4	2830
Gold (Aurum)	Au	79	196.967		1064.434	2808±2
Hafnium	Hf	72	178.49		2227±20	4602
Helium	He	2	4.00260	g	- 272.226 atm	- 268.934
Holmium	Ho	67	164.930		1474	2700
Hydrogen	H	1	1.00794	g, m, r	- 259.34	- 252.87
Indium	In	49	114.82	g	156.61	2080
Iodine	I	53	126.905		113.5	184.35
Iridium	Ir	77	192.22		2410	4130
Iron (Ferrum)	Fe	26	55.847		1535	2750
Krypton	Kr	36	8380	g, m	- 156.6	- 152.30±0.10
Lanthanum	La	57	136.906	g	918	3464
Lawrencium	Lr	103	(260)			
Lead (Plumbum)	Pb	82	207.2	g, r	327.502	1740
Lithium	Li	3	6.941	g, m, r	180.54	1342
Lutetium	Lu	71	174.967		1663	3402
Magnesium	Mg	12	24.305	g	648.8±0.5	1090
Manganese	Mn	25	54.9380		1244±3	1962
Mendelevium	Md	101	(258)			
Mercury (Hydrargyrum)	Hg	80	200.59		- 38.87	356.58
Molybdenum	Mo	42	95.54	g	2617	4612
Neodymium	Nd	60	144.24	g	1021	3074
Neon	Ne	10	20.1179	g, m	- 248.67	- 246.048
Neptunium	Np	93	237.048	L	640±1	3902
Nickel	Ni	28	58.69		1453	2732
Niobium (Columbium)	Nb	41	92.9064		2468±10	4742
Nitrogen	N	7	14.0067		- 209.86	- 195.8
Nobelium	No	102	(259)			
Osmium	Os	76	190.2	g	3045±30	5027±100

Atomic Weights, Melting and Boling Points of the Elements
(continued)

Name	*Sym-bol*	*Atomic number*	*Atomic weight*	*Foot-notes*	*Melting point (°C)*	*Boiling point (°C)*
Oxygen	O	8	15..9994	g, r	- 218.4	- 182.962
Palladium	Pd	46	106.42	g	1554	3140
Phosphorus	P	15	30.9738		44.1 (white)	280 (white)
Platinum	Pt	78	195.08		1772	3827±100
Plutonium	Pu	94	(244)		641	3232
Polonium	Po	84	(209)		254	962
Potassium (Kalium)	K	19	39.0983		63.25	759.9
Praseodymium	Pr	59	140.908		931	3520
Promethium	Pm	61	(145)		1042	3000 (est.)
Protoactinium	Pa	91	231.0359	L	1600	
Radium	Ra	88	226.025	g, L	700	1140
Radon	Rn	86	(222)		- 71	- 61.8
Rhenium	Re	75	186.207		3180	5627 (est.)
Rhodium	Rh	45	102.906		1965±3	3727±100
Rubidium	Rb	37	85.4678	g	38.89	686
Ruthenium	Ru	44	101.07	g	2310	3900
Samarium	Sm	62	150.36	g	1074	1794
Scandium	Sc	21	44.9559		1541	2836
Selenium	Se	34	78.96		217	684.9±1.0
Silicon	Si	14	28.0855		1410	2355
Silver (Argentum)	Ag	47	107.868	g	961.93	2212
Sodium (Natrium)	Na	11	22.9898		97.81±0.03	882.9
Strontium	Sr	38	87.62	g	769	1384
Sulfur	S	16	32.06	r	112.8	444.674
Tantalum	Ta	73	180.9479		2996	5425±100
Technetium	Tc	43	(98)		2172	4877
Tellurium	Te	52	127.60	g	449.5 ± 0.3	989.8±3.8
Terbium	Tb	65	158.925		1356	3230
Thallium	Tl	81	204.383		303.5	1457±10
Thorium	Th	90	232.038	g, L	1750	3800 (approx.)
Thulium	Tm	69	168.934		1545	1950
Tin (Stannum)	Sn	50	118.71		231.9681	2270
Titanium	Ti	22	47.88		1660 ± 10	3287
Tungsten (Wolfram)	W	74	183.85		3410 ± 20	5660
Unnihexium	(Unh)	106	(263)			
Unnilpentium	(Unp)	105	(262)			
Unnilquadium	(Unq)	104	(261)			
Unnilseptium	(Uns)	107	(262)			
Uranium	U	92	238.029	g, m	1132 ± 0.8	3818
Vanadium	V	23	50.9415		1890 ± 10	3380
Wolfram (see Tungsten)						
Xenon	Xe	54	131.29	g, m	- 111.9	- 107.1 ± 3
Ytterbium	Yb	70	173.04		819	1196
Yttrium	Y	39	88,9059		1552	5338
Zinc	Za	30	65.39		419.58	907
Zirconium	Zr	40	91.224	g	1852 ± 2	4377

g geological exceptional specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the Table may exceed the implied uncertainty considerably.

m modified isotopic compositions may be found in commercially available material because if has been subjected to an undisclosed or inadvertent isotopic separation. Substantial deviations in atomic weight of the element from that given in the Table may occur.

r range in isotopic composition of normal terrestrial material prevents a more precise atomic weight being given; the tabulated A_r (E) value should be applicable to any normal material.

t triple point; (graphite-liquid-gas), 3627 ± 50°C at a pressure of 10.1 Mpa and (graphite-diamond-liquid), 3830 to 3930°C at a pressure of 12 to 13 Gpa.

L Longest half-life isotop mass is chosen for the tabulated A_r (E) value.

The atomic weights presented in the above Table are the 1981 atomic weights as presented in Pure and Applied Chemistry, Vol. 55, No. 7, pp. 1101-1136, 1983.

Prefixes with Symbols used in Forming Decimal Multiples and Submultiples

Name	Symbol	Factor by which the unit is multiplied
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

The symbol representing the prefix is fixed to the unit symbol and raises the latter to the stated power:

Example: 12000 N = 12×10^{3} N = 12 kN

0.00394 m = 3.94×10^{-3} m = 3.94 mm

140000 N/m^2 = 140×10^{3} N/m^2 = 140 kN/m^2

or 1.4×10^{5} N/m^2 = 1.4 bar

0.0003 s = 0.3×10^{-3} s = 0.3 ms

Thermometric Scales

Celsius and Fahrenheit Degrees *)

°C = 5/9 (°F - 32°)				°F = (°C x 9/5 + 32°			
°C	°F	°C	°F	°C	°F	°C	°F
- 17.8	0.0	35	95.0	74	165.2	113	235.4
- 15	5.0	36	96.9	75	167.0	114	237.2
- 10	14.0	37	98.6	76	168.8	115	239.0
- 5	23.0	38	100.4	77	170.6	116	240.8
0	32.0	39	102.2	78	172.4	117	242.6
1	33.8	40	104.0	79	174.2	118	244.4
2	35.6	41	105.8	80	176.0	119	246.2
3	37.4	42	107.6	81	177.8	120	248.0
4	39.2	43	109.4	82	179.6	121	249.8
5	41.0	44	111.2	83	181.4	122	251.6
6	42.8	45	113.0	84	183.2	123	253.4
7	44.6	46	114.8	85	185.0	124	255.2
8	46.4	47	116.6	86	186.8	125	257.0
9	48.2	48	118.4	87	188.6	126	258.8
10	50.0	49	120.2	88	190.4	127	260.6
11	51.8	50	122.0	89	192.2	128	262.4
12	53.6	51	123.8	90	194.0	129	264.2
13	55.4	52	125.6	91	195.8	130	266.0
14	57.2	53	127.4	92	197.6	131	267.8
15	59.0	54	129.2	93	199.4	132	269.6
16	60.8	55	131.0	94	201.2	133	271.4
17	62.6	56	132.8	95	203.0	134	273.2
18	64.4	57	134.6	96	204.8	135	275.0
19	66.2	58	136.4	97	206.6	136	276.8
20	68.0	59	138.2	98	208.4	137	278.6
21	69.8	60	140.0	99	210.2	138	280.4
22	71.6	61	141.8	100	212.0	139	282.2
23	73.4	62	143.6	101	213.8	140	284.0
24	75.2	63	145.4	102	215.6	141	285.8
25	77.0	64	147.2	103	217.4	142	287.6
26	78.8	65	149.0	104	219.2	143	289.4
27	80.6	66	150.8	105	221.0	144	291.2
28	82.4	67	152.6	106	222.8	145	293.0
29	84.2	68	154.4	107	224.6	146	294.8
30	86.0	69	156.2	108	226.4	147	296.6
31	87.8	70	158.0	109	228.2	148	298.4
32	89.6	71	159.8	110	230.0	149	300.2
33	91.4	72	161.6	111	231.8	150	302.0
34	93.2	73	163.4	112	233.6		

*) All temperatures in this booklet are in °C

Conversion Table

1 inch	x	2.54	= cm
1 foot	x	0.3048	= m
1 yard	x	0.9144	= m
1 mile	x	1609	= m
1 square inch	x	6.452	= cm^2
1 square foot	x	0.0929	= cm^2
1 square yard	x	0.83	= cm^2
1 acre	x	4086.8	= cm^2
1 cubic inch	x	16.39	= cm^2
1 cubic foot	x	28.32	= litre
1 pint (liquid UK)	x	0.568	= litre
1 pint (liquid US)	x	0.473	= litre
1 UK quart	x	1.136	= litre
1 US quart	x	0.946	= litre
1 US gallon	x	3.785	= litre
1 UK gallon	x	4.55	= litre
1 ounce	x	28.35	= g
1 lb	x	0.454	= kg
1 short ton	x	907.18	= kg
1 long ton	x	1016.06	= kg
1 pound per sq. inch	x	0.07	= kg/cm^2

1 cm	x	0.394	= inch
1 m	x	3.281	= foot
1 m	x	1.0936	= yard
1 km	x	0.6213	= mile
1 cm2	x	0.155	= square inch
1 m2	x	10.764	= square foot
1 m2	x	1.197	= square yard
1 hectare	x	2.4711	= acre
1 cm3	x	0.061	= cubic inch
1 m3	x	35.32	= cubic foot
1 litre	x	1.76	= pint (liquid UK)
1 litre	x	2.11	= pint (liquid US)
1 litre	x	0.264	= US gallon
1 litre	x	0.22	= UK gallon
1 g	x	15.432	= grains
1 kg	x	2.2046	= lb
1 tonne	x	1.1023	= short ton
1 tonne	x	0.9842	= long ton
1 kg/cm2	x	14.22	= pound per sq. inch

$°C = {}^{5}/_{9}\,(°F - 32°)$ $°F = {}^{9}/_{5}\,(°C + 32°)$

Notes

Notes