Efficient Cooling has been written to provide a basic understanding of the complex subject of milk cooling. It is from the physiological, biological and behavioural platforms presented here that DeLaval products are developed. Our philosophy is to work in harmony with biology, the environment, and the natural processes of life, towards optimal harvesting and cooled storage of nature's most perfect food, milk.

We would especially like to thank the following for all their help (in alphabetical order):

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  Viro Food 
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- Mr G. Wever  
  Wever Architects 
  Engineer

DeLaval International AB
Business Unit Cooling

The Netherlands
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I. Introduction

Milk is one of the most important products for human consumption. Its high quality is vital, and cooling is one of the most efficient and effective ways to maintain milk's freshness. The demand on milk producers is to produce milk with a composition that meets the needs of consumers.

All chemical processes depend on temperature. At lower temperatures, chemical processes are slowed down and chemical spoilage is delayed. Milk contains several nutrients that are necessary for the life of all living beings. It is also the perfect growing medium for micro-organisms, although at 4 °C micro-organisms cannot duplicate and the microbiological spoilage of milk is avoided. After having followed the right milking and hygienic procedures, quickly cooling milk to 4 – 3 °C is the best way to avoid microbiological growth and chemical changes.

In the first human societies, snow and water were used for cooling food. Later, the theory of cooling by evaporation was developed and practised for a long time. Old Egyptian nations evaporated water in porous vases to cool their food.

Cooling media such as refrigerants (food cooling) and ammoniac (non-food cooling) are used in present-day refrigeration equipment. In the future, these cooling media will be replaced by others that have a less negative impact on the environment.

The aim of this booklet is to introduce the reader to the complex, but also fascinating process of milk cooling. We will learn the cooling principle, the reasons for cooling and the different ways of cooling milk. This book may not answer all your questions, but it can be a beginning for further reading and learning.
Where does milk come from?

For young mammals and human infants, milk is the first food ingested. In most cases, it continues to be the sole constituent of the diet for a considerable period of time.

Milk is a complex biological fluid, the composition and physical characteristics of which vary from species to species, reflecting the dietary needs of the young mammal. The major constituent of milk is water, but depending on the species, milk contains varying quantities of lipids, proteins and carbohydrates that are synthesised within the mammary gland. Also present are smaller quantities of minerals and other fat-soluble and water-soluble components derived directly from blood plasma, specific blood proteins and intermediates of mammary synthesis. The domestication of animals such as the cow, and the availability of milk surplus to the requirement of the young mammal, has meant that animal milk has also become part of the adult human diet.

Lactating animals

Many animals are kept to produce milk for human consumption. The most important are cows, buffaloes, sheep (ewes), goats, horses (mares), donkey and camels. These animals form the basis of commercial milk production in various parts of the world.

The various species produce significantly different quantities of milk. Even within the same species there are wide variations in production, largely depending on:

- Domestic purpose
- Breed and genetic quality
- Environmental conditions
- Physiological conditions
- Level of management

In general, the dominant milk-producing animals in a region reflect the geographic and climatic conditions. Goats, for example, can be successfully farmed in mountainous regions with poor grazing areas, which would be quite unsuitable for other animals.
Milk production is not always the main reason for keeping these animals. Mares, asses and camels are principally kept as draught, pack or riding animals, while milk production is a secondary concern. In many parts of the world the cow is of overwhelming importance in milk production, and in some countries milk from species other than the cow is not legally defined as milk.

Because of different circumstances for the young mammals, milk can be of different consistency. For example, reindeers that live in very cold areas need to have a thick adipose tissue under the skin. The young must consume milk with a high fat content that allows them to quickly develop this protective tissue. The pups of rats are born naked and therefore they need milk that contains the protein necessary to develop a fur coat. (for more information about milk from different lactating animals, see Alfa Laval Agri AB 1995, Chapter II).

<table>
<thead>
<tr>
<th>Species</th>
<th>Water</th>
<th>Fat</th>
<th>Casein</th>
<th>Whey protein</th>
<th>Lactose</th>
<th>Ash</th>
</tr>
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<tr>
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<td>0.4</td>
<td>0.7</td>
<td>6.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Cow</td>
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<td>4.4</td>
<td>2.8</td>
<td>0.6</td>
<td>4.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Buffalo</td>
<td>82.2</td>
<td>7.8</td>
<td>3.2</td>
<td>0.6</td>
<td>4.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Goat</td>
<td>86.7</td>
<td>4.5</td>
<td>2.6</td>
<td>0.6</td>
<td>4.4</td>
<td>0.8</td>
</tr>
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<td>Sheep</td>
<td>82.0</td>
<td>7.6</td>
<td>3.9</td>
<td>0.7</td>
<td>4.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Horse</td>
<td>88.8</td>
<td>1.6</td>
<td>1.3</td>
<td>1.2</td>
<td>6.2</td>
<td>0.4</td>
</tr>
<tr>
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<td>10.3</td>
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<td>2.0</td>
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<tr>
<td>Ass</td>
<td>88.3</td>
<td>1.5</td>
<td>1.0</td>
<td>1.0</td>
<td>7.4</td>
<td>0.5</td>
</tr>
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<td>8.6</td>
<td>1.5</td>
<td>2.8</td>
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<td>2.7</td>
<td>0.9</td>
<td>5.4</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**What is in milk?**

As J.C.T van den Berg explains: “Milk is the first food the newly born human being or mammal receives. To serve its purpose, it is a food that contains all the nutrients the newborn requires. Even beyond the suckling period, it is still the most complete food for human beings and mammals.

Some of the essential minerals and vitamins such as iron and vitamin D are, however, not present in sufficient amounts, or in optimum proportions, to fulfil the requirements for complete nutrition. During the first period of its life, the young animal therefore makes up for the shortage of certain nutrients in milk by exploiting the reserves it receives from its mother at birth, which are normally sufficient until its diet includes other foods. To make the nutrients easily consumable and digestible, they are available in a liquid state, partly as a solution, partly as dispersion or suspension. There is a wide variation in the balance of components in milk from various mammals, although the components themselves are basically the same” (van den Berg 1988, p.5)
Quantities of the various main constituents of raw milk from cows can vary considerably; between cows of different breeds and between individual cows of the same breed. The numbers in Figure II.4 give examples of the composition of milk. Water is the principal constituent and it is the carrier of all other components. Cows’ milk consists of about 87 % water and 13 % dry substance that is suspended or dissolved in the water. Beside total solids, the term solids-non-fat (SNF) is used in discussing milk composition.

**Fat**

Fat weighs less than water and exists as small globules or droplets dispersed in the milk serum (see Figure II.5). The diameter of these globules ranges from 0.1 to 20 µm (1 µm = 0.001 mm), and their average size is 3 – 4 µm. There are some 15 billion globules per ml milk. The emulsion is stabilised by a thin membrane, only 5 – 10 nm thick (1 nm = 10⁻⁹ m), which surrounds the globules and has a complicated composition.

Because of its lower weight, fat rises up and floats on the surface of milk, causing a cream layer. The taste of this fat (butter) is creamy and somewhat sweet, and it has a light yellow colour.

**Protein**

Proteins are the most important nutrient in milk and an essential part of our diet. They are present as a solution in milk, and the proteins we consume are broken down into simpler compounds in the digestive system and the liver.
These compounds are then conveyed to the cells of the body, where they are used as construction material for building the body's own protein. The great majority of the chemical reactions that occur in an organism are controlled by certain active proteins, the enzymes. Proteins are giant molecules built up of smaller units called amino acids, and a protein molecule consists of one or more interlinked chain(s) of amino acids.

**Casein**

The proteins in milk consist to 80 % of casein, which in turn is made up of a number of components that together form complex particles or micelles.

**Whey protein**

Proteins are built up completely differently and therefore also have totally different characteristics. In general, whey proteins have very high nutritional values and they are widely used in the food industry. Whey protein is also called serum protein.

**Non-protein nitrogenous compounds (NPN)**

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

**Minerals and salt**

Milk contains a number of minerals, with a total concentration of < 1 %. The most important salts are calcium, sodium, potassium and magnesium. These occur as phosphates, chlorides, citrates and caseinates.
Vitamins

Vitamins are organic substances which occur in very small concentrations in both plants and animals. Vitamins give milk its taste and are essential for normal life processes. Their chemical composition is usually extremely complex, and the various vitamins are designated by capital letters, sometimes followed by numerical subscripts, e.g. A, B1, B2. Milk contains many vitamins and among the best known are A, B1, B2, C and D. Vitamins A and D are soluble in fat, or fat solvents, while the others are soluble in water.

Enzymes

Enzymes (catalysts) are a group of proteins produced by living organisms. They have the ability to trigger chemical reactions and to affect the course and speed of such reactions, and are able to do so without being consumed.

The action of enzymes is specific: each type of enzyme catalyses only one type of reaction. Two factors that strongly influence enzymatic action, are temperature and pH. Several of the enzymes in milk are utilised for quality testing and control.

LIPASE splits fat into glycerol and free fatty acids. When milk has been damaged, lipase causes differences in taste. For example, excess free acids in milk and milk products result in a rancid taste. Many micro-organisms produce lipase.

PEROXIDASE is activated if the milk is heated to 80 °C for a few seconds. This can be used to prove the presence or absence of peroxidase in milk and thereby check whether or not a pasteurisation temperature above 80 °C has been reached.

CATALASE splits hydrogen peroxide into water and free oxygen. Milk from diseased udders has a high catalase content, while fresh milk from a healthy udder contains only an insignificant amount.

PHOSPHATASE is able to split certain phosphoric-acid esters into phosphoric acid and alcohol. Phosphatase is destroyed by ordinary pasteurisation (72 °C for 15 seconds). The phosphatase test can be used to determine whether the pasteurisation temperature has been attained.
III. Why cool milk?

In early times, people kept animals and cultivated vegetables to provide for their own needs. Animals were utilised not only for heavy work, but also as a source of food; cows were used for the production of milk and meat.

Families in these early times were almost completely self-sufficient. However, during industrialisation and profession specialisation, farmers became suppliers for consumers, and the process began whereby farms grew in size, scaling up all the time. Less farms with more animals is a trend that continues today.

The distance between the farm, the dairy and the consumer became greater, as did the time lapse between milking and the drinking of milk. Milk storage on the farm, and the time taken to bridge the gap between producer and consumer gave bacteria the chance to acclimatise and grow in this nutritious liquid. It became a problem to keep milk quality at the same level as just after milking.

If you lower the temperature of stored milk, chemical processes and microbiological growth will slow down, delaying the reduction in quality. This knowledge enabled farmers, transporters, and dairy organisations to provide milk to consumers after a time delay, without an unacceptable impact on quality. Cooling is a very good method to keep the quality of milk at a high level.

Refrigerating milk on the farm has two main aims:
– to inhibit bacterial spoilage
– to extend storage on the farm so as to decrease milk transport costs.

Full hygiene in all aspects of milk production is essential in the production of quality milk. A critical aspect is to ensure that the growth of bacteria during the storage interval must also be curtailed. At body temperature, bacteria in milk will multiply very quickly and even milk with a low initial bacteria count will sour rapidly.

Milk produced under hygienic conditions will retain good quality for a period of up to 15 to 20 hours. However, it is not only the storage temperature that is important; the cooling time to reach storage temperature, normally 4 °C, is also critical. Bulk milk coolers have been specially designed to cool the milk to 4 °C within a specified time period.
Milk hygiene and quality

One general definition of quality could be: "the consumer gets what he or she expects". Quality is extremely important, and milk producers are increasingly being expected to show that everything has been done to meet quality standards. If the producer succeeds in doing so, the consumer will have faith in the quality of the product, creating all-round benefits.

The quality of milk involves many different aspects. In this chapter we will discuss the main influences on the quality of raw milk:

– physical hygiene
– chemical hygiene
– microbiological hygiene.

Physical hygiene

Density, freezing point, osmotic pressure and acidity are examples of physical hygiene. The density of normal milk varies between 1.028 and 1.038 g/cm³ depending on the milk composition. The freezing point of milk is the only reliable parameter to check milk for dilution with water. Between individual cows, the freezing point has been found to vary from -0.54 to -0.59 °C. The acidity of a solution depends on the concentration of hydronium ions [H+] in it. When the concentrations of hydronium [H+] and hydroxyl [OH-] ions are equal, the solution is neutral (pH = 7).
Chemical hygiene

The different components of milk, especially fat and protein, may undergo chemical changes during storage. These changes are normally of two kinds, oxidation and lipolysis. The products of these reactions can cause off-flavouring in milk and butter.

OXIDATION. The oxidation of fat gives milk a metallic flavour, whilst it gives butter an oily, tallowy taste. The presence of iron and copper salts accelerates the start of auto-oxidation and the development of metallic flavour, which is also caused by the presence of dissolved oxygen and exposure to light, especially direct sunlight or light from fluorescent tubes.

When exposed to light, the amino acid methionine is degraded to methional. This is the principal contributor to the sour ‘sunlight flavour’. Since methionine does not exist separately in milk, but is one of the components of milk proteins, fragmentation of the proteins must occur incidentally for the development of the sour flavour.

To avoid the oxidation of fat and protein in milk, the most important issue is to control contact with oxygen and direct sunlight. When the milk is awaiting for transport, it must be protected from direct sunlight.

LIPOLYSIS. The break down of fat into glycerol and free fatty acids is called lipolysis. Lipolysed fat has a rancid taste and smell. High storage temperatures encourage lipolysis, but the responsible lipase cannot act unless the fat globules have been damaged. In normal farming and dairying routines there are many opportunities for fat globules to be damaged, for example by pumping, stirring and splashing the milk. In addition, sharp edges and curves in milk tubes can damage the fat globules. These details must not be overlooked when installing a milking system.

Microbiological hygiene

Food poisoning and food infections can be the result of poor microbiological milk hygiene. These dangerous microbiological aspects can be reduced by milk cooling and it is important to study them.

‘Micro-organisms’ is the collective term for ‘all small living organisms which are not visible to the eye and occupy an intermediate position between the vegetable and animal kingdoms’. They are found everywhere; in the atmosphere, in the water and in the soil. Since they break down organic material, micro-organisms play a very important role in the natural cycle.

There are thousands of micro-organic species which are important to the existence and economic structure of human society. For example, during the breakdown of dead organic material certain species form simple chemical elements
that plants can then re-use. Micro-organisms increase soil fertility and crop production, which result in more food harvested. Certain species are present in animal intestines and are essential for food digestion.

Some micro-organisms are used in food processes, for example, cheese, yoghurt, pickles, beer and wine production, as well as in acid production for food preservation.

Other micro-organisms produce toxic substances that kill other organisms. One example is the mould penicillium, which produces the substance penicillin. Other micro-organisms cause diseases in animals and plants, reducing a nation's food supply, whereas others cause food deterioration such as mould, discolouring, etc.
Bacteria

Bacteria are single-celled organisms that multiply mostly by binary fission, i.e. by splitting into two. The simplest method of classifying bacteria is according to their appearance, yet to be able to see bacteria they must first be stained, then studied under the microscope at a magnification of about 1 000. The most widely used method of staining bacteria is called Gram dyeing, and bacteria are divided into two main groups according to their Gram stain characteristics: (i) red gram negative, and (ii) blue gram positive.

Morphology of bacteria

In the word morphology, ‘morph’ stands for form and ‘ology’ for the study of. Morphology of bacteria therefore means the study of the form of bacteria. Morphological features include:

- Shape
- Size
- Cell structure
- Mobility, i.e. the ability to move in a liquid

SHAPE OF BACTERIA. Bacteria shapes can be divided into three categories: spherical, rod-shaped and spirals. The relative position of bacteria to each other is another important distinguishing characteristic. Figure 3.4 shows how spherical bacteria (cocci) occur in different formations. Diplococci arrange themselves in pairs; Staphylococci form clusters (Greek ‘staphylon’ = ‘bunch of grapes’); while streptococci form chains (Greek ‘streptos’ = ‘chain’).

The figure below shows rod and spiral-shaped bacteria respectively. The rod bacteria (bacilli) vary in both length and thickness, and they also form chains. Spiral bacteria (spirillum) are also of varying lengths and thickness, and have different numbers of turns.

Figure III.4
Morphological features of bacteria

Figure III.5
Spherical bacteria occur in different formations (adapted from Tetra Pak 1995)

Figure III.6
Rod and spiral shaped bacteria (adapted from Tetra Pak 1995)
SIZE OF BACTERIA. Cocci vary in size between 0.4 and 1.5 micrometres (1 micrometre = 0.001 mm). The length of bacilli can vary between 2 and 10 micrometres, although some species are larger and some are smaller.

CELL STRUCTURE OF BACTERIA. Like all other cells, bacteria contain a semi-liquid, proteinous substance called cytoplasm. Cytoplasm also contains starch, fat and enzymes that are involved in the metabolism of the cell. Each cell has nuclear material (DNA), the genetic information that controls the cell’s life and reproduction. In the cells of higher animals and botanical species, the nucleus, contrary to the basic substance of the cell, also contains the substance protoplasm.

The above figure shows a schematic view of the structure of a bacterium. The nuclear material is suspended freely in the basic substance of the bacteria cell (cytoplasm). The cytoplasm is surrounded by a cytoplasmic membrane that performs many vital functions, including regulation of the exchange of salts, nutrients and metabolic products between the cell and its environment. The cytoplasmic membrane is in turn enclosed in a further envelope, the actual wall of the cell. This serves as the ‘skeleton’ of the bacterium, giving it a definite shape. Some bacteria have the ability to form a protecting capsule (see Figure III.10).

MOBILITY OF BACTERIA. Some cocci and many bacilli are capable of moving in a liquid nutrient medium. They propel themselves with the help of flagella, which are similar to long hairs growing out of the cytoplasmic membrane (see Figure III.8). The length and number of the flagella vary from one type of bacteria to another. Bacteria generally move at speeds of between 1 and 10 times their own length per second, with the cholera bacterium, as one of the fastest, is able to travel 30 times its length per second.
Bacterial spore and capsule formation

The spore is a form of protection against adverse conditions, including:

- Heat and cold
- Presence of disinfectants
- Lack of moisture
- Lack of nutrients

There are various types of endospore formation in bacteria

Only a few types of genera of bacteria form spores. Of these, bacillus and clostridium are the best known. Under adverse conditions, these organisms gather nuclear material and some food reserves in one area of the cell. During spore formation, the vegetative part of the bacteria cell dies. The spore then germinates back into a vegetative cell and, if conditions become favourable again, starts reproduction.

The cell eventually dissolves and the spore is released. Spores have no metabolism. They can survive for years in dry air, and they are more resistant than bacteria to chemical sterilants, antibiotics, drying and ultraviolet light. They are also resistant to heat. For example, it takes 20 minutes at 120 °C to kill them with 100 % certainly. However, spore-forming bacteria in the vegetative state, like all other bacteria, are killed in a few minutes by boiling them at 100 °C.
Temperature

Temperature is the greatest single factor affecting bacteria growth, reproduction and food deterioration. Bacteria can only develop within certain temperature limits, and these limits vary from one species to another.

There are enormous differences between the various species of bacteria. Some species grow at temperatures close to freezing point, in exceptional cases even a few degrees Celsius below, whereas others need considerably higher temperatures.

In general, growth of bacteria in milk and milk products is considerably reduced by cooling to below 10 °C, while temperatures as low as 4 or 3 °C are required to almost completely stop almost all activity. Storage of milk at low temperatures will, however, not destroy bacteria. Freezing may lead to a slow destruction of the product as ice crystals rupture cell walls.

Maximum temperature is the temperature above which bacteria will cease to develop, while optimum temperature is the temperature at which bacteria develop best. If the temperature is increased above the maximum, bacteria are quickly killed by heat. It takes much more heat to kill bacterial spores.

Bacteria are classified into the following temperature categories:

<table>
<thead>
<tr>
<th>Category</th>
<th>Minimum °C</th>
<th>Optimum °C</th>
<th>Maximum °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychrophilic</td>
<td>-10</td>
<td>-5</td>
<td>25</td>
</tr>
<tr>
<td>Psychrotrophic</td>
<td>0</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Mesophilic</td>
<td>10</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Thermotrophic</td>
<td>25</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>Thermophilic</td>
<td>30</td>
<td>50</td>
<td>80</td>
</tr>
</tbody>
</table>

Figure III.12
Temperature conditions and classification of bacteria by temperature preference.

Figure III.13
Bacteria classification by temperature preference.
PSYCHROPHILIC are the cold-loving bacteria. They are frequently found in raw milk and usually originate from contaminated water. For this reason they are sometimes called water bacteria. In many cases, the adulteration of milk with water actually means an inoculation of the milk with this kind of bacteria.

PSYCHROTROPHIC are cold-tolerant bacteria are also found in dust from barns, feed and from other sources. If unpasturized milk is stored for long periods on the farm or at the milk plant, psychrotrophics may well spoil it. The majority of psychrotrophic bacteria are actually mesophilic, having an optimum temperature in the same range as normal mesophilic bacteria (see below).

MESOPHILIC bacteria differ from psychotrophic bacteria by being able to grow at very low temperatures. Under normal conditions they are destroyed by pasteurisation, but may be found in pasteurised milk as a result of recontamination.

THERMOPHILIC. bacteria from soil, hay or other dry and dusty feeds may contaminate raw milk on the farm. Milk solids that accumulate in improperly sanitised milking utensils are also a common source of contamination. Enormous populations of thermophilic bacteria may build up in dairy plants if milk is kept at high temperatures over long periods, or in dairy equipment that is used continuously for extended periods and not sanitised properly.

Light

Light is not essential to bacteria because they do not contain chlorophyll and synthesise food in the same way as plants do. Instead, light tends to kill bacteria as it contains ultraviolet light, a chemical activating ray that causes changes in the cell protein. In nature, the bacteria-killing effect of sunlight plays an important role, especially concerning bacteria-filled dust in the air. It is the primary reason why sunny streets and light rooms are much poorer in bacteria than dark and stuffy places.

Acidity

A suitable acidity level is very important for the proper development of microorganisms. In milk it is the pH that is decisive and not the titratable acidity. At the normal pH of milk, many micro-organisms are able to develop, but some, like mould and yeast, prefer a more acidic environment. Others, like most of the protein-fermenting bacteria, stop reproduction at increased acidity.

The acid produced by lactic acid bacteria will prevent the development of certain putrefying bacteria and actually preserve milk, although it becomes sour. Lactic acid bacteria themselves can also only tolerate a certain acidity, although not all types are equally sensitive. This means that during the process of acidification of milk, various species of lactic acid bacteria may succeed each other. Normally, acid production stops in milk at pH 4.2.
**Oxygen demand**

While all higher level organisms require free oxygen ($O_2$) to live, this is not always the case for micro-organisms. Moulds require oxygen because of their way of reproduction, and the same goes for many types of yeast and bacteria. However, other yeasts and bacteria, however, are not dependent on the presence of free oxygen, and some do not tolerate oxygen at all.

Micro-organisms can be classified into groups according to their oxygen requirements:

AEROBIC. Most yeasts, all moulds and a large number of bacteria belong here. These require free molecular oxygen for their development.

ANAEROBIC. Includes most of those bacteria that flourish in the absence of oxygen.

FACULTATIVE AEROBIC/ANAEROBIC. These organisms can grow in aerobic as well as anaerobic conditions, although often exhibit a preference for one or the other. A typical example of this group are the ordinary lactic acid bacteria, which develop more quickly at the bottom of a can or bottle than at the top. As a result, the milk at the bottom of containers starts to acidify first. Sometimes, the top layer of the milk seems sufficiently ‘fresh’ whilst the milk at the bottom is already sour.

MICRO-AEROPHILIC. These only grow in areas with a low oxygen concentration.

**Water and osmotic pressure**

Water is the major component of the bacteria cells, and considerable quantities are required for the production of new cells. Dried products, such as milk powder, are protected from bacteriological deterioration because they lack water. The drying process itself does not destroy all micro-organisms, and many survive long storage periods in dry products. Immediately after drying, the bacterial count of milk powder decreases only slowly, and it may take years before the product becomes more or less sterile. High storage temperatures will help promote the destruction of the bacteria. In addition to the water content of the product, the osmotic pressure of the water is important.

**Nutrients**

Nutrients are required for the development of micro-organisms because they supply the ‘building materials’ for new cells. Furthermore, the breakdown of complex compounds into simpler compounds delivers the energy required for the cells to function. The breaking down of compounds in combination with the production of other compound is named fermentation.
Milk is rich in nutrients and is as such an excellent nutrient for many micro-organisms. However, since the requirements of the various organisms vary, not all micro-organisms find all the nutrients they need in milk, and so not all are able to grow.

**Reproduction of bacteria.**

Bacteria normally reproduce asexually by fission. First, the size of the cell increases. The clear material then gathers in one area of the cell and divides into two identical parts. The parts that move away from each other result in two organisms that may break away or remain together, in turn resulting in different but characteristic arrangements.

The concept ‘generation time’ was introduced to indicate the rate of growth of micro-organisms. It is the time a certain species or strain requires to double in number during the exponential phase of the growth curve.

Figure III.16 shows the growth curve of bacteria transferred to a substrate by inoculation. Development phase (a) is called the ‘lag phase’, and is the delay before the bacteria start to reproduce, as they must first acclimatise to the new environment. The lag phase may also be observed in a culture that has been dormant, for example, one that has been stored at a low temperature prior to inoculation. The length of this first phase varies according to how many of the bacteria were inhibited at the moment of inoculation. If viable, growing bacteria are used and there is no period of incubation; reproduction then begins at once.
After the lag phase, the bacteria begin to reproduce quickly for the first few hours. Development phase (b) is called the ‘log phase’, because reproduction proceeds logarithmically.

During phase (b), toxic metabolic waste products accumulate in the culture. The rate of reproduction therefore eventually slows down, and as bacteria are constantly dying so a state of equilibrium is reached between the death of old cells and the formation of new ones. This next phase (c) is called the ‘stationary phase’. In the following phase (d), the formation of new cells ceases completely and the existing cells gradually die off. At the end of phase (d) the culture is extinct, hence the ‘mortality phase’.

The shape of the curve, i.e. the length of the various phases and the gradient of the curve in each phase, varies with temperature, food supply and other growth parameters.

**Bacteria in milk**

When milk is secreted in the udder it is virtually sterile. But before the milk leaves the udder, bacteria manage to enter through the teat channel and infect it. These bacteria are normally harmless and few in number, only a few tens or hundreds per ml. However, in cases of bacterial udder inflammation (mastitis), milk can be heavily contaminated with bacteria and may even be unfit for consumption, not to mention the suffering it causes the cow. There are always concentrations of bacteria in the teat channel, but most of them are flushed out at the beginning of milking. It is therefore advisable to collect the first bacteria-rich jets of milk from diseased animals.
**Infection on the farm**

In the course of handling on the farm, milk is liable to be infected by various micro-organisms, mainly bacteria. The degree of infection and composition of bacterial population depend on the cleanliness of the Cows' environment and those surfaces with which the milk comes into contact, for example, the pail/milking machine, strainer, transport churn or tank and agitator. Milk-covered surfaces are usually much greater sources of infection than the udder.

When cows are milked by hand, bacteria can get into the milk via the milker, the cow, the litter and/or the ambient air. The magnitude of the influx depends largely on the skill and the hygiene-consciousness of the milker. Certain dangers are eliminated in machine milking, but another one is added, namely the milking machine itself. A very large number of bacteria can enter the milk if the milking equipment is not cleaned properly.

**Temperature and bacteria count in milk**

Due to its very specific composition, milk is susceptible to contamination by a wide variety of bacteria. Farm milk may contain anything from a few thousand bacteria per ml, from a farm with good hygiene practices, to several million if the standard of cleaning, disinfection and cooling is poor. Daily cleaning and disinfection of all milking equipment is therefore the most decisive factor for the bacteriological quality of milk. For milk to be classed as top quality, the bacteria count (Colony Forming Units/CFU), should normally be less than 100 000 per ml. In some countries, 10 000 per ml can be reached easily.

Rapid cooling to below 4 °C greatly contributes to the quality of the milk on the farm. This treatment slows down the growth of the bacteria in the milk, thereby greatly improving its keeping qualities. The influence of temperature on bacterial development in raw milk is shown in Figure 3.14. Starting from 300 000 CFU/ml, we can see the speed of development at higher temperatures and the effect of cooling to 4 °C.

*Figure III.19
Bacterial development in raw milk (adapted from Tetra Pak 1995)*
Cooling to 4 °C, or even 2 °C, in conjunction with milking makes it possible to deliver milk at two- or three-day intervals, provided that the milk container/tank is well insulated.

In situations of non-hygienic farming and infection, the initial bacteria count rises sharply and bacterial reproduction starts at an already high level. Combined with an optimum temperature, bacterial growth is enormous. To avoid development of bacteria it is important to keep the number of bacteria as small as possible, partly by directly cooling the milk to around 4 °C.

However, it is vital to recognise that cooling is a compliment, not a substitute, for hygienic working conditions. Avoiding infections through good hygiene practices, and cooling the milk as soon as possible after milking, combine to ensure high milk quality. Cooling is a good expedient, and with efficient cooling you can help win the battle against micro-organisms.

**Principal bacteria in milk**

Many of the bacteria in milk are casual visitors. They can live, and possibly reproduce. Milk is, however, often an unsuitable growth medium for them. Some of these bacteria die when competing with species which find the environment more congenial. Groups of bacteria that occur in milk can be divided into:

- Lactic acid
- Butyric acid
- Propionic acid
- Coliform
- Putrefaction
If you wish to find out more about the positive and negative aspects of bacteria, the dairy microbiological handbooks are good reference works (e.g. R. K. Robinson 1983).

**Natural protection of milk against bacterial growth**
Among mammals, milk is the last nutritional link between mother and offspring among mammals. Besides being a complete, well-balanced diet for the newborn, milk also contains anti-microbial agents that protect the suckling young from various infectious diseases.

The knowledge that milk, and in particular colostrum (the first milk after parturition), contains immune factors essential for the survival of offspring is very old. Thousands of years ago, herdsmen recognised that newborn lambs, kids and calves must obtain the first milk (colostrum) if they want to survive.

Today, it is well documented that milk contains several antibacterial factors. The best known of these are the immunoglobulins, which can be found in high concentrations in colostrum and which provide an immediate immunisation of the newborn.

- Lacto-peroxide
- Xanathine-oxidase
- Lactoferrine
- Lysosym

Milk also contains non-specific factors as lysozyme, lactoferrin and peroxidase. This type of peroxidase, which is called lactoperoxidase, is identical to the peroxidase present in salvia and gastric juice.
**Fungi**

Fungi are a group of micro-organisms that are frequently found in nature among plants, animals and human beings. Different species of fungi vary a great deal in structure and method of reproduction. Fungi may be round, oval or threadlike. The threads may form a network, visible to the naked eye. Fungi are divided into yeasts and moulds.

**YEASTS**

Yeasts are single-cell organisms of spherical or cylindrical shape and the size of yeast cells varies considerably. For example, brewer’s yeast, saccharomyces cerevisiae, has a diameter in the order of 2 – 8 mm, and a length of 3 – 15 mm. Yeast cells of certain other species may be as large as 100 mm.

Yeast cells normally reproduce by budding, though there are other methods. Budding is an asexual process. A small bud develops on the cell wall of the parent cell. The cytoplasm is shared for a while by parent and offspring, but eventually the bud is sealed off from the parent cell by a double wall. The new cell does not always separate from its parent, but may remain attached to it while the latter continues to form new buds. The offspring cell also form fresh buds of its own, which can result in large clusters of cells attached to each other. Some types of yeast reproduce by forming spores (these are quite different from bacterial spores).

**Figure III.24**
Structure of the yeast cell (adapted from Tetra Pak 1995)

**Figure III.25**
Budding yeast cells (adapted from Tetra Pak 1995)

**Figure III.26**
Conditions for the growth of yeast

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Yeast has the same need for nutrients as other living organisms, such as bacteria.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>As for bacteria, although yeast needs less water; some can grow with very little water.</td>
</tr>
<tr>
<td>Acidity</td>
<td>Yeast can grow in a pH value range of between 3 and 7 (optimum is between 4.5 and 5).</td>
</tr>
<tr>
<td>Temperature</td>
<td>The optimum temperature is normally between 20 and 30 °C.</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Yeast can grow both with and without the presence of atmospheric oxygen. Yeast cells are facultatively anaerobic, which means that in the presence of oxygen they grow better.</td>
</tr>
</tbody>
</table>
Yeast are usually undesirable in dairy products because they often ruin them. However, Russian ‘Kefir’ and Finnish ‘Viile’ are examples from a small product group where yeasts are necessary to give the correct quality. In the brewing, wine, baking and distilling industries, yeast organisms are valuable co-workers.

MOULDS

Moulds belong to quite different groups of fungi. They consist of thread-like strands of cells called mycelium.

The mould fungi has a many-branched body called the mycelium, which may be microscopically small, or large enough to be seen with the naked eye. The mycelium consists of individual threads called hyphae. These hyphae constitute the vegetative part of the fungus. The part responsible reproduction consists of hyphae that often grow straight up and carry spores.

![Mycelium diagram](adapted from Tetra Pak 1995)

Figure III.27
Penicillium with conidiophores producing chains of conidia (adapted from Tetra Pak 1995)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>Moulds can grow on materials with a very low water content and can extract water from air.</td>
</tr>
<tr>
<td>Acidity</td>
<td>Moulds can grow in a pH value range of between 3 and 8.5</td>
</tr>
<tr>
<td>Temperature</td>
<td>The optimum temperature is normally between 20 and 30 °C.</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Moulds usually grow in aerobic conditions.</td>
</tr>
</tbody>
</table>

There are many different families of moulds. Groups that are of importance in the dairy industry include penicillium and milk mould, geotrichum candidum.
Bacteriophages

Bacteriophages are viruses, i.e. bacterial parasites. By themselves they can survive, but they can only grow or replicate within bacterial cells. They have very specific hosts, e.g. single species of strains of bacteria. Bacteriophages, or phages, can only be seen by means of an electron microscope.

The micro-organisms used in the dairy industry are called ‘starter cultures’. A starter culture is a mixture of organisms. The quality of the starter culture is preserved until after arrival at the dairy by maintaining high standards of hygiene in all steps of the processing chain.

As milk is usually contaminated with bacteriophages, it is important that the milk used for starter cultures, usually skimmed milk, is heated to inactivate the phages. Fig 3.21 shows what happens if this is not done, or if the milk is recontaminated by phages at a later time.

![Figure III.29](image1)
*Figure III.29*  
Growth of starter bacteria and phages and influence on infected starter culture (adapted from Tetra Pak 1995)

![Figure III.30](image2)
*Figure III.30*  
Structure of bacteriophages (adapted from Tetra Pak 1995)

Reproduction of phages

Phages only attack bacteria, usually young actively growing ones, within which they can reproduce. The bacteria subsequently disintegrate, releasing a crowd of 10 to 200 phages per bacterium that then attack new victims.
Conclusion

The great variety of bacteria, yeasts and moulds, and their widely varied activities, are of the utmost importance for life on earth in general, and humanity in particular. Micro-organisms in soil and water are responsible for degrading available sources of organic nourishment into forms that plants can assimilate. By doing so they also perform an indirect service to the animal kingdom.

Human beings also benefit more directly from micro-organisms. Lactic-acid forming micro-organisms, for example, can be used to preserve fodder (silage for livestock). The same principle is applied to the preparation of certain foods such as sauerkraut, green olives and cucumbers.

Micro-organisms are of paramount importance in the manufacture of dairy products such as yoghurt, cheese and cultured butter. Choice of the right types of micro-organisms is an essential factor for maximising the quality of such products.

It should be mentioned here that milk may contain residues of antibiotics emanating from treatment of cows suffering from mastitis; the most commonly occurring being penicillin. This is in spite of regulations saying that milk from cows treated with antibiotics must not be sent to the dairy.

It would be a false idealisation of micro-organisms not to mention that some of them, the pathogenic micro-organisms, are regarded as mankind’s worst enemies. Although it is true that pathogens are far outnumbered by the harmless or useful ones, their effects are much more obvious.

Almost all over the world, governments have passed laws requiring pasteurisation of milk that is produced at a dairy and intended for consumption. A typical temperature/time combination for pasteurisation is 72 °C /15 - 20 seconds, which kills all pathogens.

It is important to know that cooling is a compliment and not a replacement for hygienic working practices, and that prevention is better than cure. Avoiding infections is the first priority.

Cooling is the weapon against growth, and with efficient cooling and good care the battle against micro-organisms can be won. Milk quality rises, as does the quality of all milk products. This leaves only one winner, human health.

(For even more detailed coverage of the micro-organisms present in milk, see Tetra Pak 1995)
### IV. Milk collection

**How to transport raw milk to the dairy plant**

After milking, milk should be cooled and stored in the milk room of the farm or dairy plant. Milk for industrial processing can be transported to the dairy plant by the farmers themselves, or it can be picked up at the dairy plant. In both cases, it is possible to contract out these collection activities to third parties, for example, professional transporters.

Due to organisational or economic difficulties, it may not be possible to cool the milk on the farm. In areas far away from the dairy plant it may be troublesome to collect milk and take it directly to the plant. In such cases, especially if there are many small suppliers, it is be preferable to take milk first to a collection point, and then transport it from there to the dairy plant or milk collection centre.

**Can collection**

Milk that is available in cans, whether on the farm or at the collection point, can be picked up and transported by many convenient means of transportation (bicycles, small barrows or trucks). The cans should be protected against the sun, both while they are at the roadside awaiting collection and during transportation.
It is advisable to use insulated, or even refrigerated trucks to transport cooled milk in cans over long distances and under high ambient temperatures. When there are many individual suppliers, there are many different types of milk cans, providing logistic and cleaning problems. It is therefore advisable to use standard shape milk cans with a smooth surface.

**Bulk collection**

Milk available from the farm in bulk, for instance from farm cooling tanks, should also be picked up in bulk. It is not a good practice to use cans to transport milk that is already available in bulk (storage) tanks, because there is an extra risk of contamination. Furthermore, the temperature of milk in cans is more difficult to control than milk in bulk, and filling, emptying and cleaning of milk cans demands much labour and is costly.

Truck-mounted tanks or road tankers can be used for the transport of milk in bulk. The tanks should be insulated and may be covered by a shield to protect against strong sunshine. On the farm, or at the collection centre, the loading hose from a milk transport truck is connected to the outlet valve on the storage tank, and the milk is pumped over. Pumping is stopped as soon as the cooling tank has been emptied, thereby preventing air from being mixed into the milk. The tanker is fitted with a flow meter and pump so that the volume is automatically recorded. In other cases, the storage tank has to be calibrated to make dip-stick measurements reliable.

The tank of the bulk collection vehicle is divided into a number of compartments in order to prevent the milk from slushing around during transportation.
Milk collection points and centres

In scarcely-populated areas, or areas where individual suppliers are far away from the dairy plant and difficult to reach, milk has to be transported over long distances. Transportation to the dairy plant will also take much time. In these cases, it is advisable to collect and cool the milk in a milk collection centre (MCC) before transportation takes place.

The difference between a collection point and a MCC is mainly based on cooling and size. A milk collection point can be a small, central place where small suppliers can deliver their milk. The reception capacity is likely to be between 50 – 500 litres a day in cans or milk containers. There is no cooling equipment present at the milk collection point, so the milk should be collected and brought to the MCC within two hours after milking. At the MCC, there is always cooling equipment and, in most cases, quality testing facilities. The milk must be collected and cooled to < 4 °C not later than three hours after milking has been completed. The reception capacity of a collection centre is generally between 500 and 16 000 litres/day.
Logistic advantages

Transporting cooled milk from a storage tank at a farm or collection centre has many advantages. It enables the plant to organise an efficient system of collection and transportation. Since the milk has been cooled, it can be picked up at the farm or the collection centre at any hour of the day, without the risk of spoilage. In contrast, uncooled milk must be picked up as quickly as possible after milking, which leads to peak hours in the operation.

Each type of collection has its own advantages. Can collection is for small farms; bulk collection is for larger suppliers; and there are combinations with transport tanks for farms in between.

The most important issue is that milk must be cooled as quickly as possible. Once this has been accomplished, all parties (farmer, dairy and consumer) will benefit.

Summary

1. Milk cooling requires an adequate supply of electricity and water. These are not always available on the farm and sometimes can only be arranged at relatively high costs.

2. Even though electricity and water may be available, the volume of daily milk production may be too small to justify a cooling system, and it would be too expensive to cool a small amount of milk on the farm and too expensive to collect it. Due to regulations, smaller amounts of milk are sometimes cooled on the farm, but this milk is then expensive to transport. In such cases, it is possible to transport the cooled milk in an insulated vessel to a collecting point, where a tanker collects milk from several suppliers.

3. Bulk collection of milk on farms not only requires a supply of water, electricity and a certain daily production of milk, but also good road access for milk transport trucks.

4. If a dairy intends to introduce bulk collection of cooled milk in areas with many low producing farms (and where the milk is not cooled), substantial resources are required.
Heat – an energy difference

Material can occur in three different forms: gas, solid or liquid. Each of these forms is called a state of aggregation. For example, water (H₂O) can exist as vapour, ice or water. The transformation from one state to another occurs at a stationary point, and at this point the heat content changes, while the temperature does not. The hidden amount of heat is called latent heat.

The stationary point where ice becomes water is called the melting point, with a temperature of 0 °C, and the amount of heat needed to melt 1 kg of ice is 93 Watt. The temperature at which water becomes vapour is called boiling point, or 100 °C at 1 Bar, while the latent heat is 268 Watt. It should be noted that pressure only influences the boiling point, and not the melting point.

Evaporation heat

Many cooling processes involve the evaporation heat of a liquid. If a liquid evaporates, it needs heat. This heat is taken from the surroundings of the evaporating liquid.

An early example of cooling by evaporation can be found in ancient Egypt. Stone bottles, called Gandis, were filled with water. Because of the porous material, some of the water seeped through to the outside of the bottle wall and evaporated. This evaporation took the heat out of the bottle and therefore out of the water inside.
Cooling with basic facilities

If the milk must be stored on the farm for long periods of time, any cooling method is better than no cooling. However, if cooling facilities are basic and the time required to transport milk to the collection centre or dairy plant is comparatively short, it is advisable to deliver milk as soon as possible to the nearest milk collection centre.

Several systems are available for cooling milk. The simplest systems use water from a main or well. If abundant quantities of well water are available, the milk cans can be immersed in the well. This method, however, is not advisable if the well water is also used for drinking, because the immersion of cans easily leads to contamination of the well. Simple systems of cooling that use water will bring the milk to a temperature only 3 – 5 °C above that of the water. This means that water at a temperature of 11 – 12 °C is able to cool milk to about 15 °C (at the lowest). Apart from the fact that this temperature is still high, water of 11 – 12 °C will generally not be available in warm tropical conditions. Such conditions require artificial cooling with special equipment.

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

Surface coolers
Surface coolers consist of a series of small-diameter horizontally arranged tubes. Mounted on top of each other, these tubes terminate at each end in a header. The headers connect the tubes, thus allowing the cooling agent to circulate through them.

The warm milk is distributed over the surface of the cooler, i.e. over the set of horizontal tubes, by means of a spreader-pipe or a tray with small openings fitted on the top of the upper tube. Surface coolers may consist of two independent sections on top of each other. The upper section is cooled with water from the mains or from a well, whilst iced water or direct cooling is applied in the lower section. The surface cooling system, also called ‘open cooling system’, is simple, but requires a proper sanitisation programme. Special care must be taken to prevent airborne contamination.

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

Water tanks

The simplest cooling system involves an open tank with cold water. Milk cans have be inserted into the tank, where they are immersed in the water up to their ‘neck’. The water must be refreshed continuously or at regular intervals.

To allow de-aeration of the milk during cooling, the lids of the cans should be loosened. The tank may be covered with a lid to protect the milk from flies and dust. If well water or water from a main supply is used, this system only enables slow cooling to comparatively high temperatures. Better results are obtained by using iced water, and the cooling rate can be improved further by forced circulation of the iced water in the tank. To limit losses of cold by radiation, the tank and its cover must be insulated.
Modern cooling systems

Cooling systems transfer the heat of the milk via a cooling agent to either air or water. This transfer goes via a separated wall, so there is never direct contact with the milk. The refrigerant, or cooling agent absorbs the heat of the milk inside the evaporator. Each refrigerant has, by a certain pressure, its own boiling point. The cooling rate depends on the design of the equipment. The final temperature depends on the thermostat setting or milk flow through the plate coolers. Large differences in temperature increase the rate of cooling. High speed and turbulent motion of liquids along the wall will improve the heat transfer rate.

If milk is cooled in a modern way, electricity is needed to generate the temperature required. The electricity runs the condensing unit, which condenses the evaporated liquid and makes the process a continuous cycle.

Cooling cycle
The cooling cycle can be divided into a low- and high-pressure side

Low-pressure side
The evaporator is partially filled with refrigerant. When the compressor starts, the gas above the liquid will be sucked away. Due to this, the pressure will decrease. The liquid starts to boil as soon as the pressure sinks below the pressure of the present temperature. Parts belonging to the refrigerant will evaporate and take the heat out of the remaining cooling medium. This makes the remaining part colder. If the temperature reduces below the milk temperature, the heat will flow from the milk to the boiling refrigerant. This heat causes an amount of refrigerant to evaporate. The temperature will remain constant once the quantity of heat, which is transported by the compressor, is in balance with the amount of heat from the milk.
High-pressure side
The high-pressure side of the compressor is connected to the condenser. The purpose of the condenser is to remove the condensation heat to the surrounding area. The compressor pumps gas into the condenser. As long as the pressure remains below the pressure belonging to the condensing temperature, only the pressure will rise. As soon as the pressure rises above the pressure belonging to the condensing temperature, a heat transfer will start from the gas to the surrounding area. First the ‘super heat’ is taken away. The super heat is the temperature difference between the heated gas above boiling point and the boiling point. Condensation will start after this. To condensate with a certain capacity, a particular temperature difference is needed. The pressure will be constant as soon as the temperature difference is large enough to condensate all of the gas pumped in by the compressor.

To make this process continuous, the liquid in the condenser must be fed back into the evaporator. Since the pressure in the condenser is always higher than in the evaporator, this can be easily done by establishing a pipe connection from condenser to evaporator. If a valve is mounted in this pipe, the amount of refrigerant can be adjusted. Normally this valve is automatic, and is called the thermostatic expansion valve. This valve measures the pressure of the evaporator and the temperature of the suction pipe. The valve opens more or less according to the super heat.

Figure V.5
The individual parts of a cooling installation
### Key to figure V.5

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compressor</td>
<td>A gas pump creating low pressure in the evaporator (low temperature) and high pressure in the condenser (high temperature).</td>
</tr>
<tr>
<td>2. Pressostat</td>
<td>Mainly used for protection of the condensing side of the installation. If the pressure gets too high, the pressostat stops the compressor. Also used as protector against low pressure caused by refrigerant leakage and as a switch to stop the compressor at the end of a pump-down cycle.</td>
</tr>
<tr>
<td>3. Condenser</td>
<td>The part where the refrigerant condenses. The heat in the gas is released into the air and the gas turns into liquid.</td>
</tr>
<tr>
<td>4. Liquid receiver</td>
<td>Meant to be a storage place for the refrigerant. If the installation is in operation, the receiver is almost empty. If the installation stops and a pump-down system is installed, the refrigerant will be stored in the receiver.</td>
</tr>
<tr>
<td>5. Filter / Dryer</td>
<td>The filter is used to take all solid parts out of the liquid. The dryer is used to remove moisture present in a very small amount in the refrigerant.</td>
</tr>
<tr>
<td>6. Solenoid valve</td>
<td>In installations with a pump-down system, this valve stops the liquid flow to the evaporator.</td>
</tr>
<tr>
<td>7. Sight glass</td>
<td>Gives the possibility to check if there is sufficient refrigerant in the installation.</td>
</tr>
<tr>
<td>8. Thermostatic expansion valve</td>
<td>Gives the same amount of refrigerant, in a liquid form, back to the evaporator as the compressor takes out as a gas</td>
</tr>
<tr>
<td>9. Evaporator</td>
<td>Part where the refrigerant evaporates and consequently takes the heat out of the milk.</td>
</tr>
<tr>
<td>10. Thermostat</td>
<td>Controls the temperature of the cooled milk, switching the compressor on or off depending on the temperature.</td>
</tr>
</tbody>
</table>
**Direct expansion cooling**

This is the most common milk cooling system. The bottom of the tank has been designed as an evaporator, while the heat of the milk goes through the stainless steel wall to the refrigerant. The refrigerant evaporates, which takes the heat away from the milk. Since direct expansion tanks do not have a cold buffer, energy must always be available. In this type of system, the milk is cooled directly and agitated after arrival in the tank.

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**Icebank cooling**

In indirect cooling systems, the evaporator is situated in a reservoir filled with the heat carrier, which is mostly water. The evaporator consists of a system of coils or pipes in which the cooling medium evaporates and cools the heat carrier.
The biggest advantage of an icebank system is that it allows the cooling capacity to be stored in an isolated reservoir with a heat carrier and 'cold buffer' or 'ice buffer'. In areas where there is not sufficient energy, an icebank system provides an efficient cooling solution. The formation of ice around the pipes in the reservoir forms the cold buffer that can be used for cooling the milk. The cold buffer makes it possible for cooling in areas where energy in peak times is more expensive, or where the use of electricity is limited, and means that the cooling system can be turned off to avoid an energy rush during milking. The production of cold can occur in periods when energy is inexpensive, and can be extended over a longer period, enabling a small compressor to be used.

The energy efficiency of the indirect system is lower than that of the direct system, because cooling of the carrier demands extra energy. The energy consumption of an icebank cooler is 23 W/l. There are two types of chilled water equipment. The first is the ice builder, which accumulates ice between milkings using a small condensing unit that runs up to 18 hours a day. The second is the package chiller, which has a large condensing unit that runs only during milking.

**Pre-coolers**

Milk comes from the cows to an end unit, from where it is pumped at a constant rate through a filter to the plate cooler. The plate cooler consists of corrugated stainless steel plates. The milk flows over one side of these plates, whilst on the other side tap or well water flows in the opposite direction. When the milk leaves the plate cooler its temperature has been reduced to 2 – 4 °C above the water temperature, prior to final cooling and storage in the cooling tank.

![Figure V.9 Pre-cooling system](image-url)
Pre-cooling with cold tap water lowers the total and running costs for the plant by reducing the demand for chilled water. A prerequisite for this is, of course, a supply of inexpensive natural cold water. It is always possible to combine pre-cooling with other cooling systems to reduce the energy costs even more. If tap water has been used for pre-cooling, it is advisable to recycle the cooled or cold water by using it as drinking water for cattle. If tap water is not re-used, the costs will annul the energy costs savings, whereas if well water has been used for pre-cooling, this aspect is less important.

**Instant cooling**

Today, farms are becoming larger and larger, meaning more work, more cows and more milk – and less time between milkings. This process provides farmers with potential cooling problems, because all the milk has to be cooled and stored. The sheer quantity of milk, combined with high milk flows and longer milking periods, makes it more difficult for conventional bulk tanks to cope.

Quicker milking means greater milk amount per time. Overloaded cooling systems mean slower cooling and higher bacteria counts, and long cooling times involve prolonged agitation with the risk of buttering. Maintaining taste and quality is made more difficult, which puts the entire milk production at risk. Instant cooling is an in-line system, which cools the milk in a matter of seconds before it reaches the storage tank.
The milk goes from the cows to the end unit and balance tank, from where it is pumped at a constant rate through a filter to the plate cooler. The plate cooler is the heart of the cooling system and consists of corrugated stainless steel plates on one side of which the milk flows in one direction, while on the other side, chilled water flows in the opposite direction. When the milk leaves the plate cooler, its temperature has been reduced to a temperature 2 – 4 °C above the water temperature. The milk is pumped continuously to the insulated storage tank, where it can be kept, with occasional agitation, until collection.
**Ecombies**

Ecombies involve a two-step cooling process. It is very advantageous to combine instant cooling with pre-cooling using chilled water. Pre-cooling with cold tap or well water lowers the total costs, including running costs for the plant by reducing the demand for chilled water.

In pre-cooling, the plate heat exchanger is divided into two sections. In the first section, the milk is cooled with cold tap or well water. In the second section, the milk is cooled down to the final storage temperature using chilled water.
Cooling equipment

It is important that the consistency and quality of milk does not change during storage. In order to store milk and maintain high milk quality, proper cooling equipment is essential. When determining the suitable type of cooling equipment, the following questions must be answered:

– What is the daily milk volume?
– What is the number of milkings for storage (total storage capacity)?
– What cooling capacity is needed?
– What is the ambient temperature?
– Which are the suitable options to ensure efficient cooling?

Cooling and agitation performances

Critical factors here are the number of milkings, ambient temperature and milk cooling time.

<table>
<thead>
<tr>
<th>Classification temp.</th>
<th>Performance temp. (PT) in °C</th>
<th>Safe operating temp. (SOT) in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>38</td>
<td>43</td>
</tr>
<tr>
<td>B</td>
<td>32</td>
<td>38</td>
</tr>
<tr>
<td>C</td>
<td>25</td>
<td>32</td>
</tr>
</tbody>
</table>

• The numeral (2) designates a tank for two milkings
• The numeral (4) designates a tank for four milkings
• The numeral (6) designates a tank for six milkings

*PT, Performance Temperature – ambient temperature to be used when measuring the milk cooling temperature.*

*SOT, Safe Operating Temperature – highest limit of the range of ambient temperatures at which the equipment is required to function.*
For example, cooling equipment with the code 2BII is designed for two milkings, with calculated cooling capacity at an ambient temperature of 32°C. The cooling time (35 °C – 4 °C) for each milking will take less than three hours.

In practice, the required cooling capacity becomes lower as the number of milkings becomes larger. This is because the relative added milk volume is smaller.

**Milk cooling rate**

If a tank for two milkings is empty, or contains 50 % of its rated volume of milk at 4 °C and then 50 % of volume is added in one batch at 35 °C, all of the milk should be cooled to 4 °C no longer than the specific cooling time.

With four milkings, the respective tank stages are: empty, 25 %, 50 %, 75 % and 100 % respectively. With six milkings: empty, 16.7 %, 33.3 %, 50 %, 66.7 %, 83.3 % and 100 % of its rate volume for the same temperatures.
Material

Different materials can be used to construct a milk cooling tank, each of which has its advantages and disadvantages.

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>free from rust</td>
<td>easy to scratch</td>
</tr>
<tr>
<td></td>
<td>easy to clean</td>
<td>difficult to clean</td>
</tr>
<tr>
<td></td>
<td>easy to build</td>
<td>more expensive</td>
</tr>
<tr>
<td></td>
<td>scratch proof</td>
<td>difficult to adapt</td>
</tr>
<tr>
<td></td>
<td>shock proof</td>
<td>acid proof</td>
</tr>
<tr>
<td></td>
<td>acid proof</td>
<td></td>
</tr>
<tr>
<td>Synthetic</td>
<td>lightweight</td>
<td>easy to scratch</td>
</tr>
<tr>
<td></td>
<td>easy to build</td>
<td>difficult to clean</td>
</tr>
<tr>
<td></td>
<td>shock proof</td>
<td>more expensive</td>
</tr>
<tr>
<td></td>
<td>acid proof</td>
<td>difficult to adapt</td>
</tr>
<tr>
<td>Enamelled steel</td>
<td>free from rust</td>
<td>most expensive</td>
</tr>
<tr>
<td></td>
<td>easy to clean</td>
<td>not shock proof</td>
</tr>
<tr>
<td></td>
<td>scratch proof</td>
<td>difficult to repair</td>
</tr>
</tbody>
</table>

General

Materials in contact with cleaning water and chemicals must be resistant to cleaning and disinfecting agents, in normal conditions of dosage and temperature. This is to avoid tainting the milk.

Stainless steel

The chief alloying element in stainless steels is chromium (CR), which in concentrations above 12 – 13 % forms a passive layer on the metal. Increasing chromium content leads to a stronger passivity and thus a higher corrosion resistance. Although chromium makes the steel stainless, it cannot resist certain more aggressive environments. Other elements are therefore added to modify the structure, mechanical properties and corrosion resistance. These elements are Nickel (NI), Molybdenum (Mo), Nitrogen (N) and Copper (Cu). Stainless steel is available in many different quantities. Most milk tanks meet the quality grade AISI 304, and in special cases AISI 316.
Cleaning

Cleaning can not be passed over. The careful cleaning of a milk cooling system provides the chance to avoid infections, while cooling delays micro bacterial growth and chemical processes. Avoiding bacterial growth by quick cooling, and good cleaning clearly pays good return on any extra cost that might be incurred.

Because of the nature of the product, milk, it is necessary to clean the milking equipment after every milk turn is complete. This means that the total installation must be free from any remainders of milk, one reason being that the most important life condition for bacteria, the presence of food, is taken away. By using high temperatures and thoroughly disinfecting the installation, most bacteria will be killed. A holistic look at why and how to clean can be found in Efficient Cleaning from DeLaval.

External hygiene
– Clean the tank with soapy water of a special cleansing agent
– Pay attention to the lid and rubber seals.
– Clean valve with sweeper and check the condition of the rubber seals.

Condensing unit hygiene
– Ensure sufficient fresh air supply
– Remove dust, hay, cobwebs, etc.

Areas that need to be checked when cleaning the cooling equipment
– Inner surfaces must be smooth and clean
– Dark places, and where water has been mixed with fat and stays in drops.
– The agitator wing.
– The tank interior. If necessary, climb in the tank and clean with a brush.

Cooling medium (refrigerants)

For milk cooling, mainly halogenic cooling agents are used. These are indicated by the letter ‘R’ (standing for refrigerant), followed by a code. This code gives the following proportions in R of
– Carbon [C]
– Hydrogen [H]
– Fluorine [F]
– Chlorine [Cl]

Halogenic cooling agents are described by the following items
– In the vapour phase they are odourless and non-irritating
– They are not poisonous (except by open fire)
– They cause no corrosion
– They are neither inflammable nor explosive.
**R for Refrigerants**

**R12**
The first widely used artificial refrigerant. Yet because of effects on the ozone layer, and the negative influence of greenhouse gases, it is not longer allowed. Production has therefore been stopped.
Boiling point = \([1 \times 10^5 \text{ Pa}] (°C) – 30\%\)

**R22**
Presently the most widely used artificial refrigerant. Disadvantage is that it still has some effect on the ozone layer (5 % of R12).
Boiling point = \([1 \times 10^5 \text{ Pa}] (°C) – 40 \%\)

**R134a**
Replacement for R12, with no ozone and only a slight greenhouse effect. Disadvantages are that it requires special oil and that it is rather difficult to change an existing R12 installation to R134a.
Boiling point = \([1 \times 10^5 \text{ Pa}] (°C) – 26.5 \%\)

**R404a**
Replacement for R22, with no ozone and only a slight greenhouse effect. Disadvantages are that it requires special oil and that it is rather difficult to change an existing R22 installation to R404a.
Boiling point = \([1 \times 10^5 \text{ Pa}] (°C) – 46.4 \%\)

**R407c**
Replacement for R22, with no ozone and only a slight greenhouse effect. Disadvantages are that it requires special oil and that it is rather difficult to change an existing R22 installation to R407c.
Boiling point = \([1 \times 10^5 \text{ Pa}] (°C) – 44.0 \%\)

**R507**
Replacement for R22, with no ozone and only a slight greenhouse effect. Disadvantages are that it requires special oil and that it is rather difficult to change an existing R22 installation to R507.
Boiling point = \([1 \times 10^5 \text{ Pa}] (°C) – 46.5 \%\)

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**Norms for milk tanks**

Requirements and norms for milk cooling tanks:

**LIDS**
The opening, closing and locking operations require a positive action. Accidental opening, closing and locking shall not be possible.
AGITATORS
No hazardous part of the agitator shall come into contact with the operator. Non-protected parts shall be present on the agitator shaft, with the exception of the agitator blades and accessories for the cleaning system.

STABILITY
The tank should be constructed in a way that, under normal operating conditions, it shall not tilt or move when subjected to an external force of 750N applied at any accessible points.

THERMAL INSULATION
The tank should be provided with thermal insulation so that milk at 4 °C shall not exceed 7 °C within 12 hours when the rated volume is allowed to stand undisturbed, without refrigeration.

FREEZING OF MILK
When the tank is in use, ice shall not form under the milk surface during cooling or storage.

AGITATION OF MILK
Operation of the agitator shall not cause milk to overflow when the tank contains any volume of milk up to 100 % of its rated volume. The agitator shall be capable of producing a uniform distribution of fat throughout the milk in an operating time of not more than 2 minutes and, after that, when the milk is allowed to stand non-agitated for 1 hour.
DeLaval offers the world’s largest range of milk cooling systems for on the farm use. Able to meet virtually all raw milk cooling and storage demands, DeLaval supplies farmers with herds from one, up to more than one thousands cows.

DeLaval DX – direct expansion cooling systems

Compared to other cooling systems, the direct expansion principle gives the highest efficiency in cooling technology, combined with the lowest possible energy consumption. The stainless-steel, double-plated evaporator has a large exchange surface to ensure rapid cooling of the milk. This range includes open cylindrical tanks (from 300 – 1 800 litres); open rectangle tanks (from 1 000 – 3 000 litres), and horizontal closed oval tanks (from 1 150 – 32 000 litres).

DX with cleaning and control unit

Current modern demands regarding milk cooling and tank cleaning for closed cooling tanks are embraced in the range of DeLaval cleaning and control units. The unit is microprocessor controlled and provides: several cleaning programmes, adjustable to the conditions on the farm; and control and alarm functions, including memory to store data regarding the development of the milk quality during the time the milk is stored at the farm. A higher level of comfort can be reached with automatic dosing. The cleaning and control unit range has been developed with unique cost and environmental saving features built in, such as low water and electricity consumption.

DeLaval MC – mobile cooling systems

Mobile Cooling systems are specially developed for high quality cooling of small quantities of milk, and are used to transport the cooled milk to a pick-up point for collection by a milk tanker. Mobile cooling is especially practical when, due to lack of infrastructure, small mountain roads or small quantities of milk, the milk collection truck cannot reach the farm.
DeLaval IB – icebank cooling systems

The condensing units of icebank tanks are used to produce ice in the periods between milkings. This ice is frozen around the evaporator pipes in the lower water basin. When warm milk comes into the tank, the ice water is spayed against the outside of the inner tank. The cold water takes the heat out of the milk. These systems are used in areas where peak electricity consumption during milking should be avoided; where low night tariffs offer economical benefits; or the electricity supply in general is too weak to support larger condensing units.

DeLaval IN – instant cooling systems

This system consists of a water-cooled plate cooler, P30 clip-on, and is able to cool the milk very quickly. The chilled water used is from a water chiller or ice builder. Instant cooling is often used with large herds and milking round the clock, such as for the Voluntary Milking System (VMS). In cases where the raw milk quality is poor (due to bad hygienic conditions and milking routines), instant cooling stops growth of the bacteria immediately.

The system consists of: plate coolers; heat exchangers; condensing units with water-chillers; ice-builders; storage tanks with maintenance cooling, pumps and control unit.

DeLaval condensing units

This range is specifically designed for milk cooling on the farm using environmentally friendly freon gas. The condensing units are equipped with a piston or scroll compressor. It is available in an extensive range of capacities.
One of the most labour intensive and time-consuming jobs in dairy milk production is the milking itself, which takes place at least twice a day. Demands have therefore been growing for automatic milking systems to solve this. DeLaval offers the total automatic system, VMS, the Voluntary Milking System.

Due to a continuous low quantity milk flow, 24 hours per day, the VMS system requires an efficient, specially-designed cooling concept, and DeLaval has therefore developed a professional cooling system.

**VMS cooling**

The new IN/VMS systems uses a 300 litre receiver, equipped with pump, plate cooler and control unit. The milk flows from the VMS into the receiver tank, is pumped via a plate heat exchanger and cooled before it reaches the main cooling tank. When the main storage tank is emptied, the milk pump is blocked and the milk will stay in the receiver tank during emptying and cleaning of the tank. With this system, the milk is cooled with a P30 Clip-on Plate Cooler.

The VMS milk supply pipes to the cooling tank and instant cooling system are automatically cleaned every eight hours. The storage tank is cleaned by the unit on the tank after the milk is collected.
Cooling media and the environment

The ozone layer is a worldwide environmental concern, and the expulsion of chloride-flour-hydrocarbons (CFK’s) from cooling devices has been one of the causes. DeLaval uses environmentally friendly tank insulation materials and refrigerants, and is constantly researching for new ways to reduce any environmental impact of cooling materials.
DeLaval and the environment

DeLaval’s business mission is: “To drive progress in milk production.”

Caring for the environment is an essential part of DeLaval’s corporate strategy. By continuously improving products, processes and work place impact for both people and animals from an environmental standpoint, we will contribute to beneficial environmental conditions for customers as well as society. At the same time, we will create sustainable business activity and enhance our leading position in the market.

Guiding principles in our environmental activities:

Proactiveness
• By building up understanding and know-how together with target orientation, we will achieve a leading position in terms of the environment which will create competitive edge as well as freedom of action.
• We will exceed the minimum standards set by the authorities.

Comprehensive overview
• Environmental aspects will be considered in our decision making process. We will balance the technically possible, economically reasonable and ecologically acceptable.
• We will strive to use natural resources sparingly and prefer to use recyclable materials where available.
• Products and activities that have negative environmental risks will be avoided.
• We will strive to transfer environmentally sound technologies through our international organisation.
• We will put the same environmental demands on our suppliers as we do on our own company.
Planning and follow-up
• Environmental endeavours will be pursued continuously and systematically. These endeavours should be made an integrated part of normal operations.
• Regular follow-up and evaluation of our environmental plans will be conducted.

Development
• We will develop products and services that have less negative environmental impact.
• The total life cycle of each product will be considered, from its raw material origin and production to usage and disposal/recycling.

Marketing
• We will promote our customers’ choice of environmentally sound products by focusing on and explaining the environmental benefits.
• Marketing with environmental arguments must be based on facts and comprehensiveness.

Information and education
• By education and information, all employees should be stimulated to become environmental-conscious and to participate in the activities.
• Individual initiative for environmental improvements will be encouraged and utilised.
• Dialogue concerning environmental issues of the company will be characterised by openness and objectivity.


