Heat exchangers

The purposes of heat treatment

By the end of the 19th century, heat treatment of milk had become so commonplace that most dairies used the process for some purpose or another, such as for milk intended for cheese and butter production.
Before heat treatment was introduced, milk was a source of infection, as it is a perfect growth medium for micro -organisms. Diseases such as tuberculosis and typhus were sometimes spread by milk.
The term "pasteurisation" commemorates Louis Pasteur, who in the middle of the 19th century made his fundamental studies of the lethal effect of heat on micro-organisms and the use of heat treatment as a preservative technique. The pasteurisation of milk is a special type of heat treatment which can be defined as "any heat treatment of milk which secures the certain destruction of tubercle bacillus (T.B.) without markedly affecting the physical and chemical properties of the milk".
In considering the history of pasteurisation it is worth mentioning that although scientists everywhere agreed fairly closely on the necessary degree of heat treatment, the process was very loosely controlled in commercial practice for a long time. Milk was frequently either overheated or underheated, so that it either had a cooked flavour or was found to contain viable T.B.
In the middle of the 1930s (*JDR*:6/191), Kay and Graham announced the detection of the *phosphatase enzyme*. This enzyme is always present in raw milk and is destroyed by the temperature/time combination necessary for efficient pasteurisation. In addition, its presence or absence is easily confirmed (Phosphatase test). The absence of phosphatase indicates that the milk has been adequately heated.
Fortunately, all common pathogenic organisms likely to occur in milk are killed by relatively mild heat treatment which has only a very slight effect on the physical and chemical properties of milk. The most resistant organism is the tubercle bacillus (T.B.), which is considered to be killed by heating milk to 63 °C (145.4°F) for 10 minutes. Complete safety can be assured by heating milk to 63 °C (145°F) for 30 minutes. T.B. is therefore regarded as the index organism for pasteurisation: any heat treatment which destroys T.B. can be relied upon to destroy all other pathogens in milk.
Apart from pathogenic micro-organisms, milk also contains other substances and micro-organisms which may spoil the taste and shorten the shelf life of various dairy products. Hence, a secondary purpose of heat treatment is used to destroy as many as possible of these other organisms and enzymatic systems. This requires more intense heat treatment than is needed to kill the pathogens.
This secondary purpose of heat treatment has become more and more important as dairies have become larger and less numerous. Longer intervals between deliveries mean that, despite modern cooling techniques, micro-organisms have more time to multiply and to develop enzymatic systems. In addition, the constituents of the milk are degraded, the pH drops, etc. To overcome these problems, heat treatment must be applied as quickly as possible after the milk has arrived at the dairy.

Time/temperature combination

The combination of temperature and holding time is very important, as it determines the intensity of the heat treatment. Figure 6.1.1 shows lethal effect curves for *Coliform bacteria*, *Typhus bacteria* and *Tubercle bacilli*.
According to these curves, coliform bacteria are killed if the milk is heated to 70 °C (158°F) and held at that temperature for about one second. At a temperature of 65 °C (149°F) it takes a holding time of 10 seconds to kill coliform bacteria.
These two combinations, 70 °C/1s (158°F) and 65 °C/10s (149°F), consequently have the same lethal effect.
Tubercle bacilli are more resistant to heat treatment than coliform bacteria. A holding time of 20 seconds at 70 °C (158°F) or about 2 minutes at 65 °C (149°F) is required to ensure that they are all destroyed. There might also be heat-resistant micrococci in milk, but as a rule, they are completely harmless.

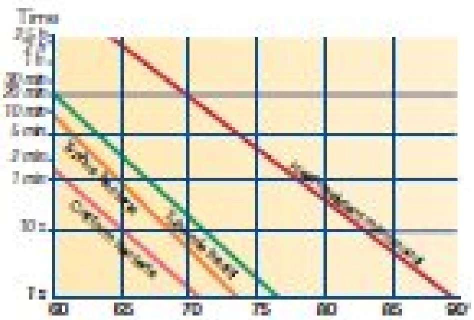

Fig 6.6.1 Lethal effect on bacteria

Limiting factors for heat treatment

Intense heat treatment of milk is desirable from the microbiological point of view. But such treatment also involves a risk of adverse effects on the appearance, taste and nutritional value of the milk. Proteins in milk are denatured at high temperatures. This means that the cheese making properties of milk are drastically impaired by intense heat treatment. Intense heating produces changes in taste; first cooked flavour and then burnt flavour. The choice of time/temperature combination is therefore a matter of optimisation, in which both microbiological effects and quality aspects must be taken into account.
Since heat treatment has become the most important part of milk processing, and knowledge of its influence on milk better understood, various categories of heat treatment have been initiated, as shown in Table 6.1.1

Table 6.1.1
The main categories of heat treatment in the dairy industry

Process	Temperature, °C	Time
Thermisation	63 – 65	15 s
LTLT pasteurisation of milk	63	30 min
HTST pasteurisation of milk	72 – 75	15 – 20 s
HTST pasteurisation of cream etc.	>80	1 – 5 s
Ultra pasteurisation	125 – 138	2 – 4 s
UHT (flow sterilisation) normally	135 – 140	a few seconds
Sterilisation in container	115 – 120	20 – 30 min

UHT treatment

UHT is the abbreviation for *Ultra High Temperature*. UHT treatment is a technique for preserving liquid food products by exposing them to brief, intense heating, normally to temperatures in the range of 135 – 140 °C (275°F-284°F). This kills micro-organisms which would otherwise destroy the products.
UHT treatment is a continuous process which takes place in a closed system that prevents the product from being contaminated by airborne micro-organisms. The product passes through heating and cooling stages in quick succession. Aseptic filling, to avoid reinfection of the product, is an integral part of the process.
Two alternative methods of UHT treatment are used:
• Indirect heating and cooling in heat exchangers,
• Direct heating by steam injection or infusion of milk into steam and cooling by expansion under vacuum.

Heat transfer processes in the dairy

One of the most important requirements of modern dairying is to be able to control the temperature of products at every stage in the process. Heating and cooling are therefore very common operations in the dairy.

Heating

Hot water, or occasionally low-pressure steam, is used as the heating medium to heat milk. A certain amount of heat is transferred from the heating medium to the milk so that the temperature of the latter rises and the temperature of the heating medium drops correspondingly.

Direct heating

Direct heating means that the heating medium is mixed with the product.
This technique is used to:
• Heat water, where steam is injected directly into the water and transfers heat to the water by both convection and conduction.
• Heat products, such as curd in the manufacture of certain types of cheese (by mixing hot water with the curd) and to sterilise milk by the direct method (steam injection or infusion of milk into steam).
The direct method of heat transfer is efficient for rapid heating. It offers certain advantages which will be considered in Newsletter 10 on long life milk production. It does, however, involve mixing the product with the heating medium, and this necessitates certain steps in the subsequent process. It also makes strict demands on the quality of the heating medium. Direct heating is forbidden by law in some countries on the grounds that it introduces foreign matter into the product.

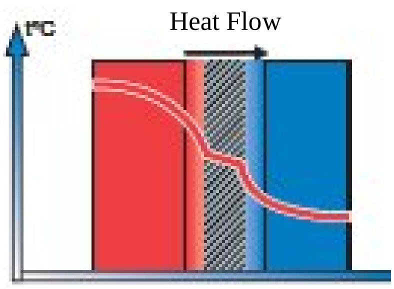

Fig.6.1.6 Heat is transferred from A heating medium to a cold product on the other side of the partition.

Indirect heating

Indirect heat transfer is therefore the most commonly used method in dairies and is used in the processing of MilkOpet® milk. In this method, a partition is placed between the product and the heating or cooling medium. Heat is then transferred from the medium through the partition into the product (Figure 6.1.6).
We assume that the heating medium is hot water, flowing on one side of the partition, and cold milk on the other. The partition is consequently heated on the heating-medium side and cooled on the product side. In a plate heat exchanger, the plate is the partition.
There is a boundary layer on each side of the partition. The velocity of the liquids is slowed down by friction to almost zero at the boundary layer in contact with the partition. The layer immediately outside the boundary layer is only slowed down by the liquid in the boundary layer and therefore has a low velocity. The velocity increases progressively, and is highest at the centre of the channel.
Similarly, the temperature of the hot water is highest in the middle of the channel. The closer the water is to the partition, the more it is cooled by the cold milk on the other side. Heat is transferred, by convection and conduction, to the boundary layer. Transfer from the boundary layer through the wall to the boundary layer on the other side is almost entirely by conduction, while further transfer to the milk in the central zone of the channel is accomplished by both conduction and convection.

The heat exchanger

A heat exchanger is used to transfer heat by the indirect method.
Several different types will be described later. It is possible to simplify heat transfer by representing the heat exchanger symbolically as two channels separated by a tubular partition.
Hot water (red) flows through one channel and milk (blue) through the other. Heat is transferred through the partition. The hot water enters the channel at a temperature of ti2 and is cooled to a temperature of t02 at the outlet. Milk enters the heat exchanger at a temperature of ti1 and is heated by the hot water to an exit temperature of t01. The temperature changes during passage through the heat exchanger are shown by the curves in Figure 6.1.7.

Dimensioning data for a heat Exchanger

The necessary size and configuration of a heat exchanger depend on many factors. The calculation is very intricate and is nowadays normally done with the aid of a computer. The factors that must be considered are :

- Product flow rate
- Physical properties of the liquids
- Temperature program
- Permitted pressure drops

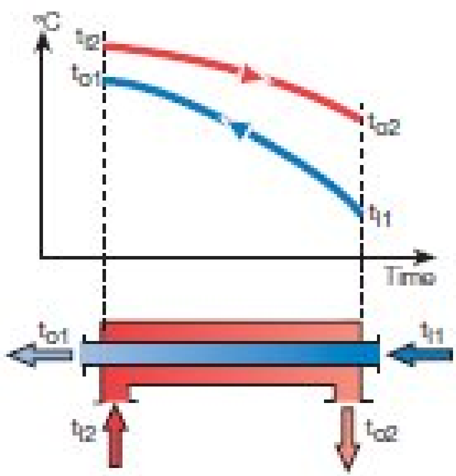

Fig 6.1.7 Temperature profiles for heat transfer in a heat exchanger

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