Inline Quality Monitoring in Milk Processing

Index

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The milk of various animals has been used a source of human nutrition for thousands of years, however it has only been in the last 200 years that techniques have evolved to produce milk for sale in high volumes. With the discovery of pasteurisation in the 19th century, it became possible to produce milk for human consumption on an even larger scale while ensuring it was bacterially safe.

Modern dairy production is now a highly automated and complex process involving many stages of processing to produce not only whole milk of standardised quality, but also secondary products such as skim milk, cream, butter, cheese and yoghurt, along with a broad range of processed food products.

This paper describes the general processes and instrumentation required in the production of whole milk, and describes the three main processes of raw milk receiving and storage, standardisation of fat content, and heat treatment for food safety. Accurate and fast control of each step of the process requires appropriate instrumentation for measuring flow, mass, temperature and pressure – instrumentation that is fast, accurate, resistant to CIP wash down, and suitable for food and beverage applications.

Milk receiving and storage

The process of milk receiving at a dairy involves the emptying of the milk delivery trucks to raw milk storage tanks to await processing. The delivery necessarily requires measuring and recording the quantity of raw milk delivered, which is challenged by the fact that the transportation will have caused some frothing of the milk, and therefore there will be entrained air in the milk (bubbles), making accurate measurement difficult. The milk reception process therefore needs to be designed well to minimise bubbles.
An air eliminator is used prior to measurement to ensure that the majority of the large coalescent foaming bubbles are removed. The larger the buffer size the greater the pressure available to collapse bubbles, which also has the advantage of a longer holding time allowing the maximum number of bubbles to escape the process before passing through the meter.

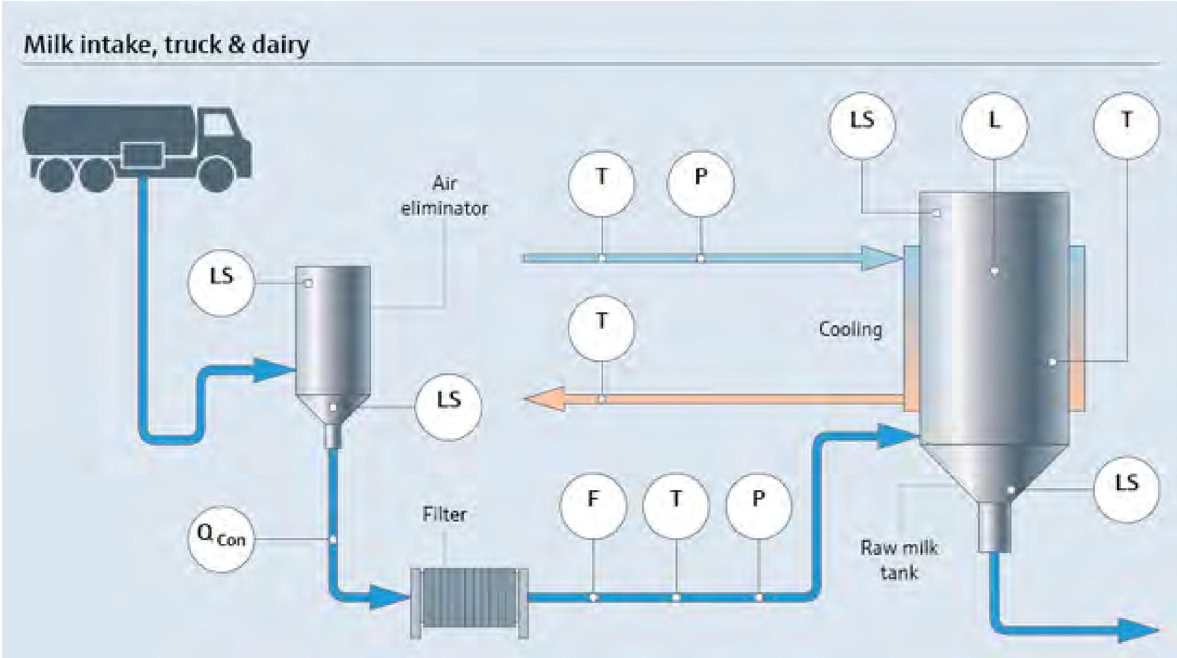

Figure1: The milk receiving and storage process

Milk receiving and storage measurement

The reception and storage of raw milk requires the elimination – as far as possible – of entrained air in the form of bubbles, and finding an accurate mass flow reading of the milk quantity, compensating for the small bubbles that remain after the air elimination stage.
Accurate mass balance and volume measurements throughout the diary process are critical for understanding such things as:

- The mass of cream or fat taken into the process, as compared with after standardisation
- Accounting for the consumption and use of the raw milk through subsequent processing
- Control of product losses at all following steps in the process.

As for all aspects of milk processing, temperature control is critical and so the accurate monitoring of delivered and stored milk temperature needs to be carried out. The storage tank will also require high level/overfill level detection and low-level detection when emptying, to find a balance between wasting milk and allowing air to be pumped into processing lines.
Measurement of milk pH at the receiving stage also ensures that milk that has been spoiled in transit is not introduced into the process.

Instruments for monitoring flow

As mentioned previously, the largest challenge in accurately measuring received milk quantity is the presence of bubbles. While a well-designed milk receiving process should eliminate most of the bubbles, it is also advantageous to choose a measurement technology that can compensate for the remaining entrained air.
In the case of measuring delivered milk quantity, the best type of instrument is a Coriolis flow meter, because it is capable of measuring the milk as a mass quantity and also measure its density, which is directly related to its fat content (see below). Such a meter can therefore provide qualitative as well as quantitative information. Recently, dual-frequency Coriolis meters have been developed that are capable of greater accuracy by being able to compensate for bubbles.

Figure2: Hygienic coriolis meter

Watch the Coriolis flow measuring principle video via below link http://bit.ly/2pz0hyS

Instruments for monitoring level

There are two places in the milk receiving and storage process where level measurement is necessary. The first is in the air eliminator and the second is the raw milk tank itself. The air eliminator, being essentially a smaller short-term storage vessel is best equipped with a capacitance level probe instrument, since fast changes in temperature and pressure will not affect its accuracy, and it offers a fast response time.

Figure 3: FMI51

In storing the milk in the storage tank, it should be remembered that the temperature of the milk will probably have risen above 4˚C and will need to be chilled and maintained at 4˚C while in storage. The milk must also be gently agitated to prevent cream separation and so it is important that the agitator is only operated when the milk level is higher than the agitator blades.

In the (often very large) milk storage tanks a hydrostatic pressure instrument provides best performance with high accuracy and stability. The instrument needs to be hermetically sealed and resistant to CIP wash-down chemicals. An instrument available with remote electronics also helps alleviate issues with access to hard-to-reach areas.

Figure 4: FMB50

For more information on instruments for monitoring level, please visit http://bit.ly/2nwpsBN

The final – and important – type of level measurement is point level sensing, which has a number of applications, including:

- overspill protection in air eliminators
- overspill protection and filling pump control for storage tanks
- minimum level in air eliminators
- minimum level in storage tanks for pump regulation and agitator control

A suitable sensor for these applications uses the vibronic measurement principle. Vibronic sensors, such as FTL50H, provide for reliable operation and are unaffected by many of the process challenges found in the receival/storage process including turbulnce, foam, bubbles, vibration and buildup.

Figure 5: FTL50H

Watch our Vibronic measuring principle video via below link http://bit.ly/2nSCkxj

Detecting spoilage

While the conditions under which the milk is stored and processed at a dairy can be well controlled, what occurs to the milk at the farm and in transport to the dairy is not within the dairy's control, and there are potential opportunities for the milk to begin to spoil before it reaches the dairy.
It is known that the spoilage of milk causes its pH to change. The pH of unspoiled milk is approximately 6.7, and as the milk spoils it becomes more acidic as lactic acid is formed. In most dairies the measurement of the pH is a manual step that is labour intensive and time-consuming, but automation of the process can be achieved with a suitable instrument.

Figure 6: CPA875

Figure 7: CPS471D

Instruments for monitoring pH

One of the problems with pH monitoring is the need to clean the pH electrode, so the ideal choice in this instance is an automated self-cleaning pH system utilising an ISFET glass-free pH electrode that can be installed in the receiving line to monitor and record the pH of every batch of milk.

Technologies are also readily available to allow for the automation of the cleaning of the pH electrode. In order to access the electrode, a retractable sterile assembly must be used, that seals the hygienic process from the outside world as the electrode is extracted and inserted. Such assemblies can be manually operated, or pneumatically driven for full automatic control. When used in conjunction with an automatic electrode cleaning system, such an assembly reduces the time and labour needed to maintain the pH measurement system.

Figure 8: CM44X

For more information on instruments for monitoring pH, please visit http://bit.ly/2ohnOBl

Minimising product loss

Due to the complexities of the dairy process, with the various processing steps, and the many pumping and storage steps along the way, there is always the chance of product loss due to various changes and malfunctions that can occur in the system. The majority of milk losses in a dairy occur during the transfer of product from one production step to the next. For example, built-in safeguards designed to prevent pumps running dry can cause pumps to stop operating and milk to be dumped to a drain. These measurements are traditionally performed by timers that are triggered by a low limit switch – a method that is not precise and is subject to downstream process issues.

As a result interface measurements (milk/air or milk/water) performed in the pipework between processing steps are preferred as they instantly detect the actual phase change and result in reduced product losses.

Instruments for minimising product loss

Minimising product loss can be achieved by using instruments that incorporate a robust, hygienic and fast sensor that can quickly detect changes in the composition of the sample. For this application, the most suitable sensor is an optical sensor, since the measurement is instantaneous and therefore provides for real time monitoring of what is flowing through the pipe. Ideally the sensor is located in the line as close as possible to the tank or process vessel that it is feeding into or before the transfer pump to protect against the pump running dry. As soon as an interface is detected the sensor can send a signal to the control system.

Optical sensors typically suitable for this purpose utilise near-infrared or visible light to detect the product interfaces or suspended solids. A sensor with a glass-free hygienic design that can withstand high temperatures during CIP processes or in heat treatment phases are most appropriate, and need to be coupled with a matching multi-parameter process transmitter.

Figure 9: OUSAF11

For more information on instruments for minimising product loss, please visit: http://bit.ly/2kOdUon

Milk standardisation

The main components of milk are water (85-88%), fat, proteins, lactose (milk sugar) and minerals (salts). There are also trace amounts of other substances such as pigments, enzymes, vitamins, phospholipids (substances with fat like properties), and gases. The relative amount of these constituents is variable, due to the natural origin of the raw product and its dependence on natural biological variation between animals, and both seasonal and locational (regional and farm-specific) variation.

The process of milk standardisation is intended to produce whole milk for retail sale that has a standardised minimum fat content, while also producing the cream (fat) by-product that can be used for secondary products such as butter, cream, yoghurt and cheese.

The composition of milk in Australia is regulated by the Food Standards Code (Standard 2.5.1), published by Food Standards Australia and New Zealand. According to FSANZ2: The standard for packaged cows' milk for retail sale requires that it contain at least 3.2% fat and 3.0% protein. Skim milk must contain a maximum of 0.15% of fat and a minimum of 3.0% protein. The Code allows milk processors to adjust the components of milk, such as lactose, protein, fat or vitamins and minerals by adding or removing those components to produce a standardised product.

Typically raw cows' milk delivered from the farm contains approximately 4% fat. The standardisation process therefore involves producing 'full cream' milk and skim milk that meet the requirements of the Standard, the remaining cream/fat being available for the manufacturing of other products. The general process of standardisation involves separating the raw milk into skim milk and cream using a centrifugal separator. Typical (rounded) figures for fat content (see Figure 9) may be that the skim milk from the separator has a fat content of 0.05%, and the cream has a fat content of 40%. Some of the cream is then remixed with the skim milk to produce full cream milk standardised to the required level of fat (in the figure 3%, and in Australia at least 3.2%).

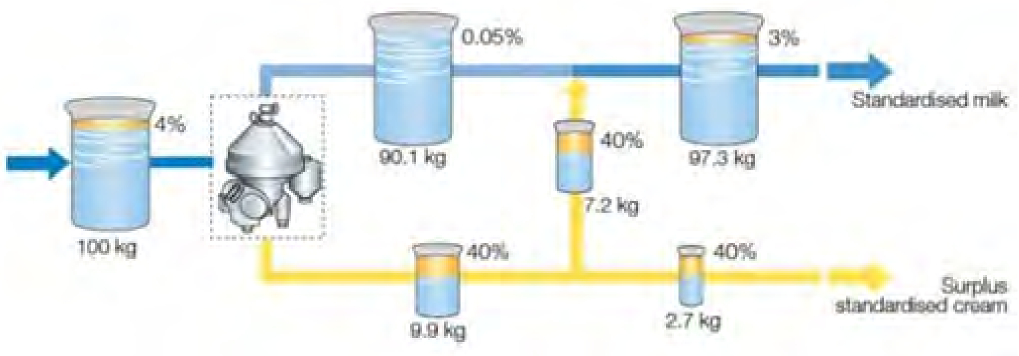

Figure10: A generalised representation of the milk standardisation process

Standardisation Measurements

For precision in the process it is not only necessary to measure the fat content during the re-mixing process, but also to measure other variable parameters such as fluctuations in the fat content of the incoming milk, fluctuations in throughput and fluctuations in preheating temperature. As most of the variables are interdependent, variations in any one stage of the process can result in deviations in all stages.
The raw whole milk is heated to 55–65°C in the pasteuriser/heat exchanger before being passed to the separator. Reliable performance of the separator also depends on the pressure in the skim milk outlet being kept constant – this pressure must be maintained regardless of downstream variations in flow or pressure, so it is necessary to monitor the outlet pressure to control a constant pressure valve.
On-line density measurement is commonly used for the control of the milk standardisation, at the re-mixing stage. The densities of skim milk and milk fat are known, although temperature-dependent (see Table 1). The density change upon the mixture addition of skim milk and cream is used to monitor and control the fat content of the standardised milk.

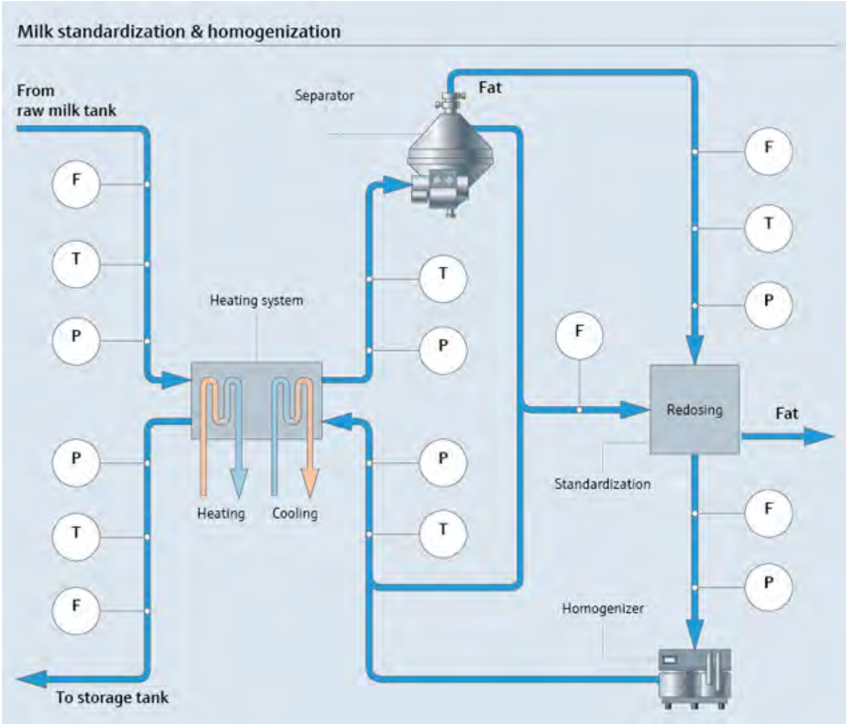

Figure11: The milk standardisation process

Product	Composition		Density (g/cm3)			
	Fat (%)	SNF (%)	4.4° C	10° C	20° C	38.9° C
Skim Milk	0.02	8.9	1.036	1.035	1.033	1.026
	0.02	10.15	1.041	1.040	1.038	1.031
Whole Milk	4.0	8.95	1.035	1.033	1.030	1.023
	3.6	8.6	1.033	1.032	1.029	1.022
	12.25	7.75	1.027	1.025	1.020	1.010
	11.3	8.9	1.031	1.030	1.024	1.014
Cream	20.0	7.2	1.021	1.018	1.012	1.000
	36.6	5.55	1.008	1.005	0.994	0.978

Table1: Density of various dairy products as a function of fat and solids-not-fat (SNF) content

Instruments for monitoring flow and density

Measuring milk flow and density can be accomplished by any number of technologies, but can be combined accurately in a single instrument by utilising a Coriolis meter. These types of meter are ideal for virtually all fluids, measuring several process parameters – including both mass flow and density – directly in the pipeline, and there are those that are available with multi-frequency technology, which maximises performance and accuracy for specific critical measurements where entrained gas is present. They can therefore be reliably used to control the standardisation processes in both cream and whole milk.

Coriolis meters designed for the dairy industry can also measure temperature and viscosity, and be configured to Viscosity, and % Milkfat.

Additionally, electomagnetic flow meters are ideal for batching, and for the receiving and feed lines of product or CIP flows. They can also handle pulsating flow and can be used for empty pipe detection. Those with integrated conductivity measurement allow for continuous monitoring of phase changes and product identification.

Figure12: Hygienic coriolis meter

Watch the Coriolis flow measuring principle video via below link http://bit.ly/2pz0hyS

Figure13: Proline Promag H100

Watch the Electromagnetic flow measuring principle video via below link http://bit.ly/2ogMQ4W

For more detailed information on Proline Promag H 100, please visit http://bit.ly/2kJQC28

Instruments for monitoring pressure

Pressure conditions in the feed line and the outlet of a separator require reliable pressure monitoring. Pressure instruments that offer a flush stainless steel or ceramic diaphragm, and a wide variety of hygienic process connections, provide the highest flexibility to retrofit into existing applications. Not only should they provide reliable and accurate pressure measurement, but they should be condensation tight and easy to clean.

Figure14: PMP55

Watch our principle of measuring pressure video via below link http://bit.ly/2nwi5Kx

For more information on instruments for monitoring pressure, please visit http://bit.ly/2ogYtsB

Heat Treatment

Raw milk can contain a range of pathogenic microorganisms, the most resistant to treatment of which is the tubercle bacillus (tuberculosis). Fortunately they can all be killed by heating the milk to a minimum of 63˚C for 10 minutes, and general practice is to maintain the temperature for 30 minutes.

In addition to pathogenic microorganisms, milk also contains other substances and microorganisms that can spoil the taste and shorten the shelf life of the milk. A secondary purpose of heat treatment is to destroy as many of these as possible, which requires more intense heat treatment than is needed to kill the pathogens. This secondary purpose for heat treatment has become more important in recent decades, as dairies have become fewer in number and larger, and are located at greater distances from both the farms and the consumers – a significant factor in the Australian dairy industry. Despite chilling milk throughout transport and storage, the time delay in processing and consuming allows more time for these bacteria to multiply – chilling milk to 4˚C slows the process but doesn't stop it completely, and once the temperature rises above 4˚C, the number the bacteria multiply rapidly (see Figure 14).

Because heat treatment has potential detrimental effects on the milk product, such as changes to flavour and appearance, or can impair secondary processing such as cheese making, the management and control of heat treatment processes is a critical factor in maintaining product quality as well as safety.

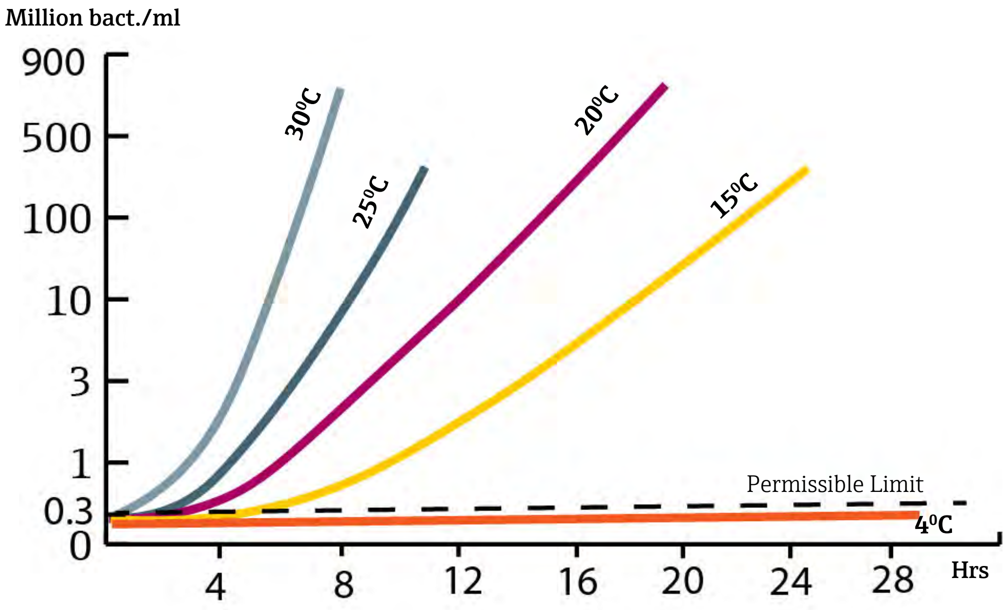

Figure15: Influence of temperature of bacterial development in raw milk

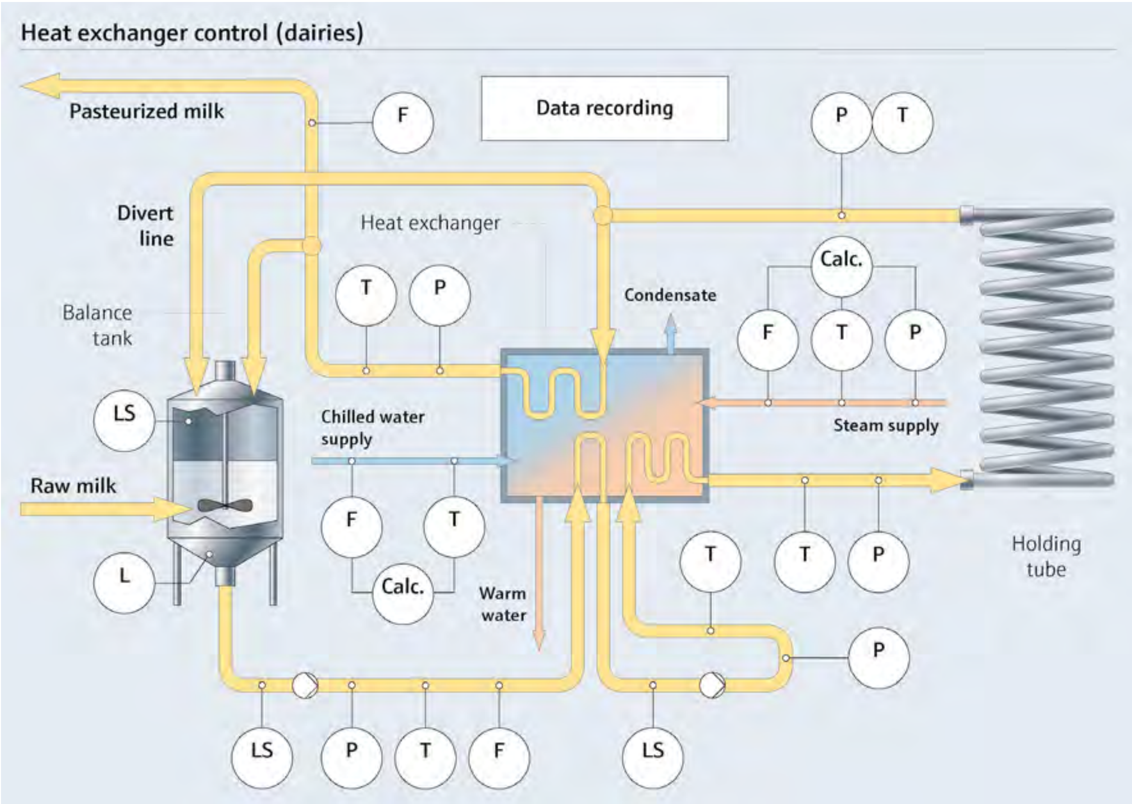

Figure16: The milk heat treatment/pasteurisation process

Pasteurisation

The minimum temperature and time mentioned above are used in a process known as LTLT (low temperature, long time) pasteurisation. Modern dairies in contrast use a process called HTST (high temperature, short time) in which the milk is heated to 72-75°C for a shorter time of 15-20 seconds. It is easier to maintain the higher temperature for this shorter time in a holding tube, than it is to maintain a lower temperature for longer. After pasteurisation, the milk must be cooled to 4°C for packaging and transport. To ensure the minimum time in the holding tube is met, an accurate measurement of the volumetric flowrate (m^3/s) through the system is required. As the holding tube contains a fixed volume of milk (m^3), the volumetric flow rate allows for the calculation of time that the milk was in the system ($m^3/s/m^3 = s$).

The most energy-efficient way to achieve the various stages of heating and cooling is to use a multiple stage heat exchanger in which the hot pasteurised and raw cold milk are used as part of the heat transfer process. By this method, the hot pasteurised milk is cooled in the heat exchanger by transferring some of its heat to not only a cooling fluid such as cold water, but also to the cold raw milk in an adjacent section of the exchanger. In this way, less steam heating is required to bring the raw milk up to the required temperature. Regenerative heat exchange in this way can recycle as much as 95% of the heat from the pasteurised milk.

The risk with regenerative heat exchange is that any leak that may occur internally in the heat exchanger could lead to raw milk contaminating the pasteurised milk. To mitigate this risk, the flow of hot milk entering the heat exchanger for cooling must be pumped through the heat exchanger at a higher positive pressure than that for the raw milk by using a booster pump.

Measurement required - Flow

As a continuous process, empty lines could create problems for the heat exchanger, whether it be the raw and pasteurised milk product, the heating steam or the cooling fluid. It is therefore necessary to make sure that the flow rate through the heat exchanger is constant and balanced, and also to monitor the flow and consumption of steam.

Instruments for monitoring flow

The requirements of flow measurement in dairy heat treatment (sanitary, accurate and robust) can all be fulfilled with the use of a magnetic flow meter.
The accuracy of a typical magnetic flow instrument used for heat treatment flows is unaffected by large flow variations. Since the magnetic measurement principle is virtually independent of pressure, density, viscosity and temperature, it is ideal for monitoring flow in the heat treatment process and can provide empty pipe detection.

Figure17: Promag H100

For more detailed information on Proline Promag H 100, please visit
http://bit.ly/2kJQC28

Watch the Electromagnetic flow measuring principle video via below link http://bit.ly/2ogMQ4W

Measurement required - Pressure

The next most important parameter to measure is pressure. As stated above, when using regenerative heat exchange, the differential pressure between the raw milk and pasteurised milk sides of the heat exchanger must be measured and maintained to ensure there is a higher pressure on the pasteurised milk side. Under normal continuous process conditions, the pressure would normally be constant and within a certain range. Abnormal variations in the pressure and flow rate anywhere in the process may be an indication of a leak or potential failure in the heat exchanger or elsewhere. The same applies for heating and cooling fluid lines, where a leak could result in these fluids also contaminating the milk.

Instruments for monitoring pressure

Monitoring pasteurised milk pressure will require a high level of hygienic safety, and so an appropriate instrument designed to be food safe with a ceramic or stainless steel sensor membrane, and tolerant of CIP wash-down chemicals is required (Figure 18).

Level measurement in the balance tank is also important to monitor, and is typically performed using hydrostatic pressure measurement, in the same way as for the raw milk receiving tanks.
As the pasteurisation process is critical to food safety, the process must legally be recorded and the information made available to authorities for quality auditing purposes if required. The recorder must meet the FDA requirement for having tamper proof data storage and personalised access authorisation with electronic signature (FDA21 CFR11) which is fulfilled by recorders such as the RSG45.

Figure18: PMP55

Watch our principle of measuring pressure video via below link http://bit.ly/2nwi5Kx

For more information on instruments for monitoring pressure, please visit http://bit.ly/2oqYtsB

Thermisation

In some cases it is not possible to pasteurise and process all the milk immediately after reception, and the storage of raw milk for days or even hours, despite chilling, can result in degradation of the milk before it is even processed.

Thermisation is a process carried out by many dairies to temporarily inhibit bacterial growth. It involves preheating the milk to a temperature just below the pasteurisation temperature for about 15 seconds.

To prevent bacteria from multiplying after thermisation, the milk must be rapidly chilled to 4°C or below and it must not be mixed with untreated milk. This process should be applied only in exceptional cases – ideally pasteurisation of the incoming milk should be completed within 24 hours of receiving.

Measurement required: Temperature

As the most critical process in relation to food safety, the milk heat treatment process must be accurately and continuously monitored and recorded, with correct temperature being the most primary consideration. Accurate and fast-responding temperature instruments are required at a number of points in the process:

- Raw milk stored in the balancing tank and flowing into the heat exchanger, as well as the pasteurised milk after cooling must be monitored to be sure it remains at 4°C
- The milk leaving the heat exchanger and entering the holding tube as well as the milk leaving the holding tube must be monitored to ensure the pasteurisation temperature is achieved and compared to ensure that the temperature is maintained for the required holding period. This data must be continually logged for food safety audit purposes. If the temperature is not maintained for the required time, then the milk must be diverted back to the balancing tank to avoid compromising food safety. Fast temperature response is essential.
- The heat exchange process also requires the right flow of water for cooling and steam for heating to maintain the correct temperature flows, so temperature instruments are also required to monitor and control the temperature of these fluids.

If a thermisation process is being used for stored raw milk, then fast-responding temperature instruments will also be required to monitor the heating and cooling process, as well as the storage temperature.

Instruments for monitoring temperature

Due to the rapid heating and cooling used in milk processing, temperature sensing in milk heat treatment must be fast and accurate. It is essential that temperature instruments that are used have the fastest possible response, such as this in Figure 19 which can have a t90 response time of under 1.5 seconds for the best process control. It is also important that they have a high vibration resistance (better than 60g) for plant safety.

To achieve these requirements, modern temperature sensors use a new kind of thin film sensor element that is soldered directly into the sensor tip. The film design improves upon previous generation sensors, as its performance is not affected by vibration that is commonly found in process. Soldering the thin film sensor directly onto the tip also results in extremely fast temperature response as it ensures ideal heat transfer from the process to the sensor element.

Due to its criticality, the temperature sensors must also be calibrated regularly, to ensure that the minimum temperature requirement is met. Frequent calibrations, however, can impact on plant uptime as the process needs to be stopped and isolated to allow the sensors to be safely removed. To alleviate this hassle, newly designed temperature sensors provide for two piece construction, whereby, the first piece (thermowell) is permanently welded into the process and the second piece (temperature measuring element) is inserted into the thermowell by means of a simple bayonet connection. An example of such a sensor is shown below in Figure 19.

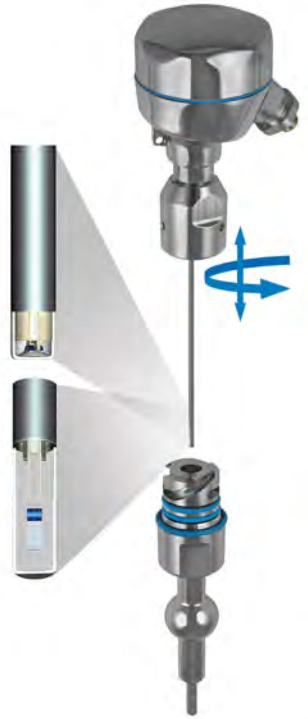

Figure19: iTHERM TM 411

For detailed information on iTHERM TM411, please visit http://bit.ly/2koB7jT

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