SECTION 5
MILK PRODUCTION and QUALITY
CHAPTER 48
ANATOMY AND PHYSIOLOGY OF LACTATION

“Remember a cow is a mother and her calf is a baby”

Introduction

Very early in the development of the dairy industry in Britain, the way to treat cows for milking was described as follows:

“...She shall then milk the cow boldly, and not leave stretching and straining of her teates, till one drop of milk more will come from them; for the worst point of housewifery that can be, is to leave a cow halfe milkt; for besides the losse of milk it is the only way to make the cow dry, and utterly unprofitable for the dairy. The milkmaid, whilst she is milking, shall do nothing rashly or suddenly about the cow which may a fright or amaze her; but as she came gently, so with all gentleness she shall depart.” From C. Markham (1660). The English housewife – a way to get wealth.

The same principles still apply for present-day dairies using modern equipment.

Anatomy of the udder

The udder of a mature dairy cow normally weighs about 10 to 25 kg and consists of four individual glands, also referred to as quarters. Each quarter is drained by a teat at the bottom of the quarter. There is no flow of milk between quarters. The total milk storage capacity of the udder may be as high as 35 kg.

The udder is a skin gland connected to the abdominal cavity through the inguinal canal. Blood and lymph vessels, as well as nerve fibres, enter the udder from the abdominal cavity through this canal, which forms a tube about 10 cm long.

Seen from the back, the udder is divided into a right and left half by the udder or intermammary groove. From a side view, the fore and rear quarters are more smoothly joined together not having such a distinctive groove. The hind quarters are usually larger than the fore quarters and may secrete 25 to 50% more milk than the fore quarters with the ratio between back and fore quarters being 60 to 40%.

The udder is attached to the body by the following ligaments:

1. The medial suspensory ligament, which divides the udder into a right and left half (Figure 48.1), and
2. The lateral suspensory ligaments, which form a fibrous layer around the outside of the glands joining the medial suspensory ligaments on the lower surface of the glands.

The lateral suspensory ligaments are chiefly fibrous, whereas the medial suspensory ligaments are more elastic fibres. Filling the udder therefore stretches the medial ligaments to enlarge the storing capacity of the udder. When these ligaments weaken, the udder tends to separate from its close adherence to the abdominal wall and the udder is described to be breaking away. Connective tissue penetrates and traverses each quarter, thus giving shape and further support to the udder. A big udder may contain a large volume of connective tissues and little gland tissue; udder size is, therefore, not always a true indication of the productive ability or capacity of a cow.
The udder should ideally shrink during the milking process and must therefore be completely elastic when empty.

It is important for the udder to extend well forward for the maximum utilisation of the space available underneath the body. This feature is essential, since the udder must be large enough to contain all the milk that may be secreted between milking sessions. This results in the udder expanding, i.e. becoming larger, by about one-third of its normal size. This expansion increases the milk-carrying capacity of the udder by approximately 60%, while the remaining 40% of the milk secreted can be accommodated in the natural storage spaces of the udder.

The shape and size of the teats that drain the four glands are independent of the shape and size of the udder. In addition to the four normal teats, about 40% of cows have one or more supernumerary teats, usually without the presence of glandular tissue. These teats usually occur behind the rear teats.

Milk collecting system

The teat opening, or streak canal, is situated in the lower end of the teat and is surrounded by a sphincter muscle. This muscular walled canal, which is 0.5 to 1.0 cm long, prevents dirt entering the udder and milk escaping before milking commences. The diameter of the streak canal and the tonus of the sphincter muscle determine the ease of milking a cow. At the upper end of the streak canal loose folds of tissue, called the Furstenberg’s Rosette, press down against the opening of the streak canal and assist in preventing the escape of milk from the udder.

The teat cistern has a diameter of about 1 cm with a capacity of 30 to 50 ml of milk immediately above the teat opening. In the teat cistern, several fairly well-defined circular membranes are found. This may sometimes form a septum across the teat, preventing the flow of milk. If this happens, the septum has to be pierced with a special needle to enable normal milk flow.

The udder cistern, also called the lactiferous cistern, with a capacity of 100 to 400 ml of milk, follows immediately beyond the teat cistern and is situated in the udder. There is no definite separation between these two cisterns resulting in their being more or less continuous. From the gland cistern five to 20 large milk collecting ducts branch and rebranch into very small collecting tubules, each eventually ending in an alveolus (Figure 48.2).
An alveolus consists of a single layer of milk producing cells attached to the inside of a spherical basement membrane. This cell layer of epithelial cells surrounds the lumen, the hollow inside of the alveolus into which the milk is excreted. A dense myoepithelial (muscle tissue) and vascular (blood-vessel) network surrounds the alveolus (Figure 48.3). Each lumen drains into a small milk-collecting tubule. These small tubes flow together forming larger milk ducts.

The alveoli occur in large numbers in the udder and have a diameter of 0.1 to 0.3 mm. They are grouped together in lobules by connective tissue; each lobule containing about 200 alveoli. All the lobules draining into the same milk duct are described as a lobe.
Milk secretion

Each alveolus is surrounded by a dense network of fine blood-vessels which provide the milk synthesising cells with a continuous supply of nutrients for the synthesis of milk. There are three phases identified during milk secretion:

- Synthesis by the cells of the alveolar epithelium;
- Discharge from the epithelial cells into the alveolar lumen; and
- Storage in the alveolar, ducts, and cisterns.

Directly after milking, the lumina are almost empty, the epithelium folded, and the cells themselves are largely devoid of any secretion. As the producing cells draw the raw materials for milk synthesis from the blood, synthesised secretory products fill the interior spaces of the cells before leaving through the walls of the apex to fill the lumen with milk.

About 500 kg of blood pass through the udder during the production of one kg of milk. Some milk constituents move unchanged from the blood to the milk, while others are synthesised by the epithelium. Casein and lactose, for example, are found only in milk, while milk fat comprises glyceride combinations not found elsewhere in the body.

Udder pressure and secretion rate

Changes in the secretion rate and intramammary pressure in the udder during milk secretion as affected by milking interval are shown in Figure 48.4.

![Figure 48.4. The decrease in milk secretion rates (a) and increase in udder pressure (b) as affected by the length of the milking interval](image)

Milk is continually synthesised at a rate of about 1 to 2 mℓ/g glandular tissue per day. At the completion of milking, when all available milk has been removed, pressure within the teat cistern is at atmospheric levels, but within an hour after milking, pressure within the udder increases by about 1 kPa as milk residues fill the collapsed teat and udder cisterns. Thereafter, pressure initially increases slowly for 5 to 6 hours, and then more rapidly at 2 to 4 kPa at the end of normal milking intervals. The pressure at this stage depends on the length of the interval between milking sessions, udder capacity, and the yield of cows. The pressure in the udder is also greater in the hind quarters than in the front quarters, as well as in early lactation.

Milk is secreted at an inverse rate to mammary pressure. This relationship is, however, virtually linear for the first 10 hours. Thereafter, with an extension of the interval, the rate of synthesis slows down, showing a marked reduction after about 24 hours. After about 36 hours, when udder pressure may be as high as about 7 kPa above atmospheric pressure, milk secretion stops altogether.

There are indications that the apparent decline in secretion rate of most of the milk constituents, as the milking increases, is due to their absorption during storage, rather than a true decline in secretion rate.

Once the rate of milk secretion has been depressed by delaying milking, it does not immediately revert to normal when milking resumes. For example, the yield obtained in an 8-hour interval following a 24-hour interval, is 25% less than when the 8-hour interval was preceded by another normal 8-hour interval.
Milking frequency and milk production

Long intervals between milking sessions cause the udder pressure to increase to high levels, slowing down the secretion rate. By shortening milking intervals, an increase in daily production is possible.

The interval between milking sessions is a critical element of dairy management as both the number of milking sessions in a 24-hour day and the duration of the intervals between milking sessions are important. At high milk yields and lower storage capacity in the udder, milk must be removed more frequently from the udder to avoid a reduction in the milk secretion rate. Intervals longer than 12 hours between milking sessions should be avoided.

In South Africa, at least 90% of cows are milked twice a day. Milking at exactly equal intervals of 12 hours is ideal, but is rarely practiced because of the unsocial hours which it imposes on the milkers and management. The average intervals for large herds are usually about 14 and 10 hours, i.e. at 05:00 and 15:00 per day. However, based on research results, a ratio even as wide as 16 to 8 hours does not reduce milk yield by more than 4%. This means that the lower milk yield could be weighed up against milking at more sociable hours, for instance to start milking at 07:00 and 15:00 every day.

Milking cows three times instead of twice a day increases milk yield by 5 to 25%, provided cows are fed adequately. When no extra feed is provided to compensate for the higher milk yield, cows will lose body condition (live weight), which would affect the milk yield of cows in the following lactation negatively. Increasing the number of times cows are milked per day, results in higher production increases in older cows in comparison to first lactation cows. A decrease in udder pressure is often only partly responsible for the higher milk yield, because better feeding and management may also contribute.

No conclusive proof is available that milking frequency influences the composition of milk produced daily. Some research showed a slight decline in fat percentage in milk when cows are milked thrice instead of twice a day. This is probably because of the higher milk yield.

Milking cows four times per day may lead to an increase in milk yield of 5 to 10% higher than that of cows milked three times per day. This increase is mainly due to better feeding and overall management.

Milking cows only once a day throughout the lactation reduces lactation milk yield by 5 to 10% in comparison to twice a day milking. Once-a-day milking is often applied under pasture-based conditions when pasture production is limited or when cows are at the end of the lactation period when milk yield is at a low level.

The milk let-down reaction

The largest percentage of milk in the udder is stored in the lumen of the alveoli and in the small milk ducts. Due to the small diameter of these ducts, capillary forces prevent the drainage of the milk.

Milk in the alveoli and ducts cannot be removed from the udder using normal means without the cooperation of the cow. Only the small quantity of milk present in the teat and udder cisterns and in the larger milk ducts can be removed. This milk is described as the fore-milk and is only a small percentage of the total milk stored in the udder.

At the commencement of milking, only the fore-milk is therefore immediately available. Hereafter an interruption of milk flow usually occurs. This is especially noticeable in cows that have not been stimulated correctly before milking has started. Before the initiation of the main milk flow, i.e. before milk let-down occurs, the nervous system of the cow must first be stimulated to let milk down.

The nervous reflex responsible for milk let-down begins with the stimulus produced by the suckling of the calf, or the presence of milkers, or the sounds of the milking machine. In normal milking routines, udder washing at the beginning of the milking process usually serves as the stimulus for milk let-down.

The teat base, i.e. where the teat joins the udder, is richly supplied with nerve centres and a massage (when being washed) or suckling action on this area produces a strong stimulus. The nerve impulse travels to the hypothalamus of the brain, which activates the pituitary gland to release the hormone oxytocin into the blood which carries it to all parts of the body. When it reaches the udder, it causes the myoepithelial cells surrounding each alveolus to contract, decreasing the size of the lumen of
the alveolus, forcing milk out of the ducts. The small ducts also shorten and widen to facilitate the movement of milk from the alveoli into the larger ducts. As a result of the above, the teat and udder cisterns, as well as the larger milk ducts, become distended with milk, resulting in the hardening of the udder and teats and an increase in intra-mammary pressure. Milk let-down has occurred and the cow can now be milked. A period of 45 to 60 seconds elapses between the time when oxytocin is released into the bloodstream and when it arrives in the udder.

About 15% of the initial milk volume cannot be removed from the udder during a thorough, normal milking process and is known as residual milk. Removal of residual milk is, however, possible by the injection of oxytocin. This procedure is of no practical use as the residual milk does not affect the daily milk yield of cows.

**Oxytocin levels in blood serum**

The average oxytocin level in the blood serum of dairy cows is about 8.0 ± 0.11 μU/ml. As a result of cow stimulating cows increases the level of oxytocin which reaches a peak concentration of about 25 μU/ml within two minutes. The peak concentration may vary considerably, e.g. from 11 to 65 μU/ml between cows. After peak, the concentration of oxytocin declines sharply, reaching pre-stimulation levels within about four minutes.

The maximum concentration obtained and the time required to reach this peak is dependent on the following factors:

- **Type of stimulus**
  Hand stimulation, e.g. a 30-second udder wash, is a strong stimulus and results in maximum oxytocin levels in the blood within 1 to 2 minutes. The normal pulsator action of the milking machine causes a more gradual increase and a lower peak concentration. The peak is obtained in about double the time than with hand stimulation (Figure 48.5).

- **Breed of cow**
  Holstein-Friesian cows are easier to stimulate than Jersey cows.

![Figure 48.5. The oxytocin concentration before, during and after manual (■) and milking machine (□) stimulation](image)

**Oxytocin concentration and milkability**

During the 1960’s, researchers in New Zealand found that hand-stimulated cows, i.e. a 40-second udder wash immediately prior to machine-milking, resulted in 16% more milk and 32% more fat yields than cows not stimulated by hand. Low producing Jersey cows were used in the study. These results contributed to the conclusion that high oxytocin levels, as a result of the strong milk let-down reaction, also cause a high pressure in the udder which is required for the complete removal of milk. Since the oxytocin levels in the blood and udder pressure start to decline within minutes after stimulation, it is accepted that to ensure optimal milk flow that the milk process should start within one minute after stimulation.

The results of more recent research, using high performing Holstein cows, showed that production increases because of hand-stimulation, to be about 0 to 2%. This small beneficial effect does not contradict the
necessity of stimuli and circumstances contributing to a strong milk let-down reaction. It is, however, evident that the degree of stimulation necessary to ensure complete milking is dependent on factors such as breed, production level and stage of lactation. The conclusion is that in the case of a modern, high genetic merit, high producing dairy cow, the stimuli from the normal milking parlour routine are sufficient to ensure a satisfactory milk let-down reaction and that deliberate stimulation would not be required.

Reasons for this change in emphasis on the necessity for the specific stimulation action include the following:

- High producing dairy breeds and cows are stimulated more easily.
- Due to the culling of cows from the herd on the basis of milk production, it follows that those cows which do not respond adequately to the particular milking parlour routine for a specific dairy will be culled because of low milk yields. The evolution of modern milking machines and methods thus resulted in the selection for animals requiring a minimum of stimulation.

### Effect of time interval between stimulation and milking on milk characteristics

High oxytocin levels are maintained in the blood for only a short period. The duration of the milk let-down reaction is therefore also short. Research has shown that the half-life of oxytocin is about 3 minutes. Because optimum milkability is only obtainable when both oxytocin levels and udder pressure are high, it is important that the milking unit is attached to the udder before the oxytocin concentration in the blood starts to decline, which is usually within one minute after stimulation. When the interval between stimulation and the attachment of the milking unit is delayed, milk characteristics are adversely affected (Table 48.1).

Even short delays between stimulation and the start of milking may have the following results:

- a decrease in milk yield,
- a higher stripping volume,
- a longer machine-on time,
- a decrease in the maximum milk-flow rate,
- a longer time to reach peak-flow rate,
- a lower fat percentage in milk, and
- shortening the lactation period because of earlier drying up.

#### Table 48.1. Milking characteristics caused by delays between pre-stimulation and the start of the milking process

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Delay (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Total milk yield (kg)</td>
<td>11.2</td>
</tr>
<tr>
<td>Stripping (kg)</td>
<td>0.2</td>
</tr>
<tr>
<td>Total machine-on time (min)</td>
<td>7.6</td>
</tr>
<tr>
<td>Peak-flow rate (kg/min)</td>
<td>2.7</td>
</tr>
<tr>
<td>Time to reach peak flow rate (min)</td>
<td>1.9</td>
</tr>
</tbody>
</table>

### Inhibition of milk let-down response

Inhibition of the milk let-down response has been observed in a number of species as the result of emotional disturbances, such as cows being frightened, in pain, anger, etc. The immediate cessation of the milk-flow is caused as a result of a nerve stimulus causing the adrenal gland to liberate the hormone adrenaline (epinephrine) into the blood stream. The mechanism by which adrenaline causes the inhibition is not absolutely clear. It is, however, known that adrenaline causes the constriction of the blood vessels in the udder. Another possibility is that adrenaline prevents the release of oxytocin.
Blood circulation through the udder

The quantity of blood in the body of cows varies from 5.8 to 8.5% of live weight. In young cows and dry cows, the percentage is lower than in older cows and in cows in milk. It is known that for each 1 kg of milk secreted, 150 to 500 kg of blood must pass through the udder.

To maintain a high secretion rate, an adequate vascular system supplying and draining blood to and from the udder is essential. All the blood vessels to and from the udder occur in pairs, one vessel for each half of the udder. The arteries carrying blood to the udder include the following:

- **The external pudic artery**
  This is the most important artery carrying blood to the udder. It enters the udder through the inguinal canal and is then known as the mammary artery.

- **Perineal artery**
  This artery reaches the udder through the pelvis and supplies blood to the posterior dorsal part of the udder.

The blood leaves the udder through the following veins:

- **The external pudic vein**
  This leaves the udder through the inguinal canal

- **Subcutaneous abdominal vein**
  This vein flows from the udder under the abdomen and enters the body cavity through the milk-well, posterior to the sternum.

Elements of the milking routine

An efficient and fixed milking routine, which is understood by the milkers and which cows are used to, is a very important component of milk production. Low milk yields, low fat tests, short lactations and the spread of mastitis, often result from an inefficient milking routine.

The basic steps in the milking routine are as follows:

1) **Washing the udder**

Proper washing of teats and udders before milking (Figure 48.6) serves a three-fold purpose
- controlling bacterial contamination of the milk,
- stimulating milk let down, and
- protecting against mastitis.

Dirt and manure clinging to the cow’s udder and teats contain many millions of bacteria per gram of dirt. To prevent this dirt and bacteria from being washed into the milk during milking, it is essential that the lower part of the udder, and especially the teats, are thoroughly washed before milking. Water at room temperature, luke-warm water (approximately 40°C) or, preferably, water containing a disinfectant, should be used for this purpose. The following methods could be used:
- **Bucket method**: This is a method commonly used in small-scale dairies but is, from both a hygienic and a convenience point of view, not recommended to be used. The disadvantages are that, unless individual washing-cloths are being used for each cow, both the washing-cloth and water in the bucket become a source of bacterial contamination, increasing the possibility of spreading mastitis among cows.

- **Hose with spray nozzle**: This method is hygienic, convenient and practical, especially in milking parlours. The washing action can either be done with the bare hand or with a single-service washing-cloth (one cloth per cow). Devices which measure disinfectant into the water-line are available.

- **Automated udder washing**: This can be done either in the milking-parlour or in a preparation stall. A water sprayer located on the floor or a preparation stall is automatically turned on by the cow entering the stall.

  The effectiveness of udder washing is affected by:

  - the thoroughness of dirt removal from the teats and lower part of the udder,
  - preventing the unnecessary wetting of the upper parts of the udder as well as the groin area of the cow, and
  - drying the teats and udder before commencement of milking, preferably with a single-service paper towel (Table 48.2).

### Table 48.2. The effect of different udder washing procedures on the bacterial content of milk

<table>
<thead>
<tr>
<th>Washing procedure</th>
<th>Bacteria per mL of milk</th>
<th>Clean udders</th>
<th>Very dirty udders</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>None</td>
<td>5120</td>
<td>1010 – 16900</td>
<td>7530</td>
</tr>
<tr>
<td>With water, no drying</td>
<td>8840</td>
<td>1550 – 28350</td>
<td>18540</td>
</tr>
<tr>
<td>Water and drying</td>
<td>3 160</td>
<td>750 – 15000</td>
<td>14400</td>
</tr>
<tr>
<td>Disinfectant, no drying</td>
<td>2 150</td>
<td>405 – 18750</td>
<td>11250</td>
</tr>
<tr>
<td>Disinfectant and drying</td>
<td>750</td>
<td>172 – 4605</td>
<td>1930</td>
</tr>
</tbody>
</table>

Udder washing usually serves as a stimulus for the milk let-down reaction and should begin about one minute before applying the milking machine.

**ii) Testing for mastitis**

This involves squeezing a small quantity of milk from each teat, either onto a stip cup or into the paddle which is used for performing the California Mastitis Test (CMT). This action allows the milker to ensure that the teat orifice is not blocked and to check for mastitis, blood and other abnormalities in milk (Figure 48.7).
iii) Attaching the teat cups (or milk cluster)

The teat cups should be attached as soon after udder preparation as possible (Figure 48.8). After stimulation, the milk let-down reaction wears off within minutes, and if the cow is not completely milked within this time, the volume of residual milk will increase.

![Figure 48.8. Attaching the teat cups on the teats](image)

iv) Stripping

This is the term given to the methods used to remove more milk after normal milk flow has ceased. Hand stripping gave way to machine stripping, usually achieved by downward pressure on the claw and by massaging the udder (Figure 48.9).

![Figure 48.9. Stripping of milk from the udder](image)

The purpose of stripping is to ensure that all the available milk is removed from the udder. Various research reports have indicated that a higher yield is obtained when stripping is included in the milking routine. In a trial conducted in Germany, in which only the right half of the udders of first lactation cows were stripped after milking, those halves produced 6.8% more milk and 9.2% more fat per lactation than the unstripped halves of the udders.

The necessity and advantage of stripping depend largely on the thoroughness of stripping cows after milking. Complete milking-out is largely dependent on:
- effectiveness of stimulation,
- timely utilisation of milk let-down reaction, and
- efficiency of the milking machine.

To cease machine stripping does not normally have a detrimental effect on udder health, although air rushing in when machine stripping is done, may increase the risks of mastitis.

Stripping, being time-consuming, is often not done at the end of the milking routine. The responsibility to ensure that the cows are thoroughly milked out should, however, not be neglected.

v) Removing the milking unit
The milk clusters can be removed once the milk-flow rate has dropped to below about 20 mℓ/min. This is done by cutting off the vacuum from the clusters and by gently drawing the teat-cups off the udder (Figure 48.10). Continuing to milk cows after the milk flow has dropped results in over-milking with the following disadvantages:

- increases the erosion of the teat orifice,
- this may increase the number of new mastitis infections, while
- available machine-time is wasted.

Figure 48.10. Removal of the milking cluster from the teats

vi) Rinsing the milking units
Although very often omitted from the milking routine, the milking units, in an effort to minimise the spread of mastitis organisms from cow to cow, may be rinsed between cows. This can either be done by dipping the teat cups first in a pre-rinse (water) and then in a sanitising solution, or by back-flushing with water which may contain a disinfectant.

The effect of cluster flushing on new mastitis infection rates is not clear. It is, however, known that the bacterial population on liners can be reduced, although not eliminated, by flushing, for example, with water at 85°C for 5 seconds, or by back-flushing with either cold or hot water which may or may not contain a disinfectant, such as hypochlorite or iodine.

Indications are that back-flushing, even with cold water, reduces new infection rate as caused by streptococcal but not by staphylococcal mastitis. There is, however, also evidence that inter-cow cluster pasteurisation, which is much more effective than any type of cluster flushing, will only give moderate reductions in new infection rates when teat disinfection is practiced.
vii) Teat disinfection
The most effective single element in the control of new udder infection among lactating cows is teat disinfection immediately after milking (Figure 48.11). Teat dipping (disinfection) can be done by either dipping the teats or by spraying the disinfectant on the teats.

Teat dipping has the following advantages:
- destroys bacteria left on the teat at the end of milking,
- eliminates and prevents colonisation of the teat orifice by pathogenic bacteria, and
- assists in the prevention and healing of teat lesions, particularly when emollients such as glycerol are included in the formulation.

This practice can reduce new mastitis cases by approximately 50%. A range of disinfectants, including sodium hypochlorite, iodophors, chlorhexidine, dodecyl benzene, sylphonic acid and others, are employed for this purpose.

Figure 48.11. Teat disinfection using a spray method after milking and the removal of the milking clusters

As with teat dipping, the amount of disinfectant used and the efficiency of teat coverage by spraying depend primarily on the skill of the operator. If care is taken to cover the teats, the time to spray teats will be longer, while using more disinfectant than teat dipping.

The effectiveness of germicidal teat dips in reducing new infections caused by Streptococcus agalactiae and Staphylococcus aureus is well-documented. The majority of these teat dips are, however, not very effective in eliminating new coliform infections. The use of latex teat dips, which were designed to form a physical barrier over the teat opening to prevent environmental bacterial contamination between milking sessions, may be more effective against the latter organism. A reduction of for example 76% was found in the number of new coliform infections when an acrylic latex teat dip without germicide was used.

In closing
Milk production is a continuous process in the udders of dairy cows until all the alveoli and ducts are filled up. Removal of milk by milking cows initiates milk synthesis. The milk let-down is affected by the release of oxytocin, while it is blocked by the secretion of adrenaline. Treating cows calmly before and during milking will result in high milk let-down and milk production. The interval between udder stimulation and milking unit attachment should be within one minute, as high oxytocin levels are maintained in the blood only for a short period. High producing dairy cows are stimulated more easily. First lactation cows not adapting well to the milking parlour management will be culled early as their milk yields will be affected negatively.
CHAPTER 49

THE COMPOSITION OF MILK

Variation is the only constant characteristic of milk composition

Introduction

Milk is defined as the undiluted, fresh lacteal secretion obtained by the complete milking of one or more healthy cows, excluding colostrum, which is secreted within 15 days before and about 5 days after calving down.

Bulk milk obtained from different sources may differ widely in composition. Even milk from an individual cow may vary from one to another milking session, e.g. such as morning and evening milking, as well as the total milk from day to day. The variation in milk composition is a result of the influence of a long list of physiological, inherited, and environmental factors.

The gross composition of milk based on a large number of milk samples collected from a variety of sources and including different breeds is presented in Table 49.1.

Table 49.1. The gross composition of cow’s milk

<table>
<thead>
<tr>
<th>Component</th>
<th>Content (%)</th>
<th>Total solids (%)</th>
<th>Solids not fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>87.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fat</td>
<td>3.7</td>
<td>3.7</td>
<td>-</td>
</tr>
<tr>
<td>Proteins</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Lactose</td>
<td>4.9</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>Minerals</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>12.8</td>
<td>9.1</td>
</tr>
</tbody>
</table>

The components, other than water, are known as the total solids (TS) and the total solid minus the fat content is the solids-not-fat (SNF). In average milk, these two groups of components amount to about 12.8% TS and 9.1% SNF. All milk contains the same gross components, although in varying proportions (Table 49.2).

Table 49.2. The average composition of the milk of various mammals

<table>
<thead>
<tr>
<th>Species</th>
<th>Water (%)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>Lactose (%)</th>
<th>Minerals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woman</td>
<td>87.4</td>
<td>3.8</td>
<td>1.6</td>
<td>7.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Cow</td>
<td>87.2</td>
<td>3.7</td>
<td>3.5</td>
<td>4.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Goat</td>
<td>87.0</td>
<td>4.3</td>
<td>3.5</td>
<td>4.3</td>
<td>0.9</td>
</tr>
<tr>
<td>Ewe</td>
<td>80.7</td>
<td>7.9</td>
<td>5.2</td>
<td>4.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Buffalo</td>
<td>82.8</td>
<td>7.4</td>
<td>3.6</td>
<td>5.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Camel</td>
<td>87.6</td>
<td>5.4</td>
<td>3.0</td>
<td>3.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Mare</td>
<td>89.0</td>
<td>1.6</td>
<td>2.7</td>
<td>6.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Ass</td>
<td>89.0</td>
<td>2.5</td>
<td>2.0</td>
<td>6.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Reindeer</td>
<td>63.3</td>
<td>22.5</td>
<td>10.3</td>
<td>2.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Since different batches of milk may differ noticeably as it is affected by a number of biological factors, and to ensure that buying and selling of milk in the trade is conducted on an equitable basis, the composition of any batch of milk should be known. Knowing the composition of milk is important for the following reasons:

- The composition of milk determines the yield and composition of manufactured dairy products. For example, the Cheddar cheese yield from 100 kg milk containing 3% fat is about 8 kg in comparison to about 10 kg from milk containing 4% fat.
- Milk in the so-called fresh-milk trade must comply with specific minimum requirements. Although these may vary, depending on the controlling authority, the minimum requirements for full-fat fresh milk according to the Act on Agricultural Product Standard (Act 119 of 1990) should be:
  - Fat : minimum 3.3%
  - SNF : minimum 8.3%
  - Protein : minimum 3.0% (on fat-free basis)
- The composition of milk is a component in the breeding programme of a dairy herd. Total milk production is negatively correlated to fat and protein percentages. This means that fat and protein percentages decrease when milk yield increases. While it is important to increase the total milk yield of dairy cows, the ultimate aim in breeding should be to increase the fat and protein yield per lactation of dairy cows.
- In most quality payment schemes, the fat and protein content of milk determines about 80% of the farm-gate price.

**Milk fat**

### Physical characteristics

The percentage fat in bulk milk varies between 3 to 5%, although the variation may be wider in the milk of individual cows. The fat in milk exists in the form of small globules, averaging in size from about 0.001 to 0.005 mm in diameter. The surface of these globules is coated with an absorbed layer of phospholipids and proteins. This layer is commonly known as the fat globule membrane and plays an important role in preserving the individual identities of the globules. About 1.5 to 3.0 billion of these tiny globules may occur in 1 mℓ of milk. The size of the globules is dependent on the following factors:

- **Breed of cow**: The fat globules in the milk of dairy breeds with higher fat percentages, like Jersey and Guernsey, are larger than those in the milk of breeds with lower fat percentages like Holstein-Friesians. The average fat globule in Guernsey milk is 80% larger than that of Holstein milk. Variation in globule size does not cause the daily variation in the fat test of the milk of individual cows.
- **Stage of lactation**: Cows later in lactation have smaller fat globules in their milk. The fat globules are usually the largest during the first two weeks of the lactation with the most rapid rate of decline occurring during the next two months of the lactation. Thereafter, the rate of decline is slow, although...
continuing to the end of the lactation. This decline in globule size is an important factor as late lactation milk is more susceptible to the development of a rancid taste.

- **Individual cows:** The size of globules from different cows from the same breed may vary to a great extent.

Fat globules float around in the milk in a true oil-in-water emulsion with the fat being the dispersed phase. Fat globules are kept apart by:
- The viscosity of milk.
- The fat globule membrane – this membrane has to be removed or broken before two fat globules can unite. Agitation, as in churning, breaks the membrane and the globules coalesce to form butter granules.
- A negative electric charge that is present on the globules.

Due to the difference in the specific gravity (SG) of milk fat (SG of 0.93) and skim milk (SG of 1.036), the globules in undisturbed milk will, with time, rise to the surface to form a cream layer on top of the milk. Due to this, it is of utmost importance to stir milk thoroughly before a sample of bulk milk is collected for analysis. Sampling from a bulk tank should be preceded by at least five minutes of stirring.

### b. Chemical composition

Milk fat, like the majority of animal fats, consists chiefly of triglycerides of fatty acids. It also contains varying quantities of other components as indicated in Table 49.3.

A triglyceride can be defined as an ester (combination) of one glycerol molecule with three molecules of fatty acids. A triglyceride can thus be represented as follows:

\[
\text{Glycerol + fatty acid 1 + fatty acid 2 + fatty acid 3 = triglyceride + H}_2\text{O}
\]

At least 18 different major fatty acids, some of which are shown in Table 49.4, are found in milk fat.

#### Table 49.3. The components of milk fat

<table>
<thead>
<tr>
<th>Components</th>
<th>Content in fat(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triglycerides</td>
<td>98 - 99</td>
</tr>
<tr>
<td>Phospholipids (lecithin)</td>
<td>0.2 - 1.0</td>
</tr>
<tr>
<td>Sterols (cholesterol)</td>
<td>0.2 - 0.4</td>
</tr>
<tr>
<td>Free-fatty acids</td>
<td>Trace amounts</td>
</tr>
<tr>
<td>Fat-soluble vitamins</td>
<td>Trace amounts</td>
</tr>
</tbody>
</table>

#### Table 49.4. The chemical formula, melting points and content of some major fatty acids in milk fat in comparison to soy beans

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Formula</th>
<th>Melting point</th>
<th>Content in milk fat (%)</th>
<th>Content in soybeans (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butyric</td>
<td>C(_3)H(_6)COOH</td>
<td>-8°C</td>
<td>2.9</td>
<td>-</td>
</tr>
<tr>
<td>Capric</td>
<td>C(_8)H(_14)COOH</td>
<td>16°C</td>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td>Stearic</td>
<td>C(_18)H(_34)COOH</td>
<td>69°C</td>
<td>15.0</td>
<td>-</td>
</tr>
<tr>
<td>Oleic</td>
<td>C(_18)H(_32)COOH</td>
<td>14°C</td>
<td>31.9</td>
<td>25</td>
</tr>
<tr>
<td>Linoleic</td>
<td>C(_18)H(_36)COOH</td>
<td>-31°C</td>
<td>4.5</td>
<td>55</td>
</tr>
</tbody>
</table>
Butyric acid \((\text{CH}_3 - \text{(CH}_2)_2 - \text{COOH})\) is an example of a volatile fatty acid. Being volatile, it is partly responsible for the pleasant aroma given off when butter is heated.

Stearic acid \((\text{CH}_3 - \text{(CH}_2)_{16} - \text{COOH})\) is an example of a saturated long-chain fatty acid and is described as a hard fat with a melting point of 69°C.

Oleic acid \((\text{CH}_3 - \text{(CH}_2)_{7} - \text{CH=CH - (CH}_2)_{7} - \text{COOH})\) has the same amount of carbon atoms as stearic acid, but contains 2 hydrogen atoms less. It is therefore classified as an unsaturated fatty acid and has a lower melting point (14°C) and is thus a soft fat.

Linoleic acid \((\text{CH}_3 - \text{(CH}_2)_{5} - \text{CH=CH - (CH}_2)_{2} - \text{CH=CH - (CH}_2)_{5} - \text{COOH})\), similar to stearic and oleic acids, also contains 18 carbon atoms, but has 4 hydrogen atoms less than stearic acid, as well as two unsaturated bonds. Because this type of fatty acid contains more than one double bond, it is termed a poly-unsaturated fatty acid. Linoleic acid has, because of its unsaturation, a very low melting point and is therefore classified as a very soft fat.

Any three fatty acids, or even three molecules of the same fatty acid, may combine with a single glycerol molecule to form a triglyceride. A wide variety (theoretically \(18^3 = 5832\)) of different triglycerides may thus appear in milk fat. All different triglycerides would be in an individual milk fat globule.

The fat percentage in milk is currently determined by means of infra-red analysers. This method is based on the absorption of the infra-red light by specific chemical bonds in the triglycerides.

It is important to indicate that the fatty acids in normal milk are chemically bound to the glycerol molecule and thus do not contribute to the acidity of milk. When milk, however, turns rancid, fatty acids are hydrolysed (set free) from the glycerol molecule by the enzyme lipase. Free fatty acids responsible for the rancid taste then appear in the milk contributing, although to a very minor extent, to the acidity.

The percentage of the different fatty acids in milk differs as a result of the following factors:

- **Breed:** In the milk of breeds producing high fat milk there is a smaller percentage of low melting point fatty acids, e.g. butyric and oleic acid, resulting in Jersey cows producing fat that is usually firmer than that of Holsteins.
- **Feed:** Feeds, like green pasture and linseed oil, containing a high percentage of low melting point fatty acids, e.g. oleic and linoleic acid, result in a soft fat, whereas dry roughages produce a firm fat.
- **Stage of lactation:** Fatty acids are affected by lactation stage, e.g. butyric acid has a maximum value during the first month of lactation and decreases during succeeding months, reaching a minimum at the end of the lactation. Stearic and oleic acids are high in early lactation, while it decreases until mid-lactation and increases again to the end of the lactation period.

Higher levels of low melting point fatty acids in milk result in softer fat, thereby improving the spreadability of the butter made from such milk.

c. The precursors of milk fat

Propionic acid is indirectly the main glycerol precursor. In cows, it is converted into glucose outside the mammary gland. The glucose is converted into glycerol inside the gland. Fatty acids may result from the following three sources:

- **Short chain organic acids:** Acetic acid makes the most important contribution to the synthesis of fatty acids in the mammary gland. Acetic acid results from the fermentation of digestible carbohydrates, e.g. hemi-cellulose which occurs in high concentrations in fibre-rich feeds in the rumen. A certain amount of roughage in the diet is required to stimulate this fermentation process and to maintain the normal fat percentage in milk.
- **Fat depots in the animal body:** this is a major source when cows are underfed.
- **Ingested fats:** Fats in the diet contribute approximately 25% of the milk fatty acids.

d. The role of milk fat in milk and milk products

Fat is probably the most important component in milk. Its effect is seen mainly in four categories, i.e. the economy of milk production, human nutrition, food flavour, and the physical properties of milk products.
In the past, most payment systems for milk were based largely on the fat content of milk. In South Africa, payment for protein was incorporated into the payment scheme in 1983. Since milk fat is still relatively expensive compared to other milk components, it is obvious that the cost of dairy products depend on their fat contents.

Milk fat, as with other fats, is a rich source of energy, yielding approximately 9 Kcal/gram (1 cal = 4.185 Joules). Secondly, it serves as a carrier of the fat soluble vitamins A, D, E and K, and thirdly, milk fat contains significant amounts of the so-called essential fatty acids i.e., linoleic acid and arachidonic acid.

The most distinctive role that milk fat fulfills in dairy products concerns the flavour of foods. Milk fat is responsible for the rich, pleasing flavour of many dairy products such as butter, cheese, and ice cream. On the other hand, it is also notable that the milk fat is significant in many flavour problems, such as rancidity and oxidised flavours, which may occur in dairy products.

The fine body and texture in most dairy products is determined in many instances by milk fat.

<table>
<thead>
<tr>
<th>Protein fraction</th>
<th>Content in milk (%)</th>
<th>Average of total N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casein</td>
<td>2.7</td>
<td>76 - 79</td>
</tr>
<tr>
<td>Albumin</td>
<td>0.3</td>
<td>9</td>
</tr>
<tr>
<td>Globulin</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>Proteose-peptone</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Non-protein nitrogen</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>Total protein</td>
<td>3.5</td>
<td>100</td>
</tr>
</tbody>
</table>

2. Casein

Casein is defined as the protein fraction that precipitates from skim milk when the pH decreases by acidification to a pH of 4.6 to 4.7.

The casein content in milk varies from 2.3 to 3.8%. It is the main protein fraction of milk and is not produced anywhere else in nature. In milk, casein occurs as a fine colloidal suspension in combination with calcium and is often termed calcium caseinate. The colloidal particles have a diameter of approximately 0.0001 mm, being 10 times smaller than the fat globules in milk.

Casein is precipitated in milk by:

- Acids: This usually happens when the normal pH of milk of about 6.6 sours to a pH level of 5.2 to 4.5. It is this precipitation of the casein that causes sour milk to thicken or coagulate.
- Alcohol: When milk and 68-70% alcohol are mixed in a 1:1 ratio, the casein precipitates if acid development has already occurred. This is the basis for the well-known alcohol (Alizarol) test by which raw milk is graded before being picked up on the farm.
- Rennin: The enzyme rennin used in cheese-making coagulates milk at a normal pH-level within a short time frame.
- Heavy ions: The presence of an excess of...
heavy ions, e.g. Ca++ and Mg++, causes the coagulation of casein.

Casein, being a high quality protein as it contains all the essential amino acids, is very much in demand in the food industry. Dairy products, such as cheese and milk powder, contain a high percentage of casein.

Casein also has a number of non-food uses and is being used in the paper coating, glue, plastic, paint, textile, and leather industries.

3. Albumin and globulin

These two proteins are in true solution in milk and are not precipitated by rennet or by normal acidification to a pH level of 4.7. During the cheese-making process, they are thus not coagulated and remain in the whey. For this reason these proteins are called the soluble or whey proteins. Their total percentage in milk is about 0.5 to 0.7%.

Both albumin and globulin are precipitated by heat (about 68°C or higher). This is the reason why colostrum, which may contain up to 10% of these proteins, thickens when it is heated.

Immunoglobulin (IG), a fraction of globulin, is present in normal milk in low concentrations, while occurring in colostrum in much larger quantities. These proteins are of unique importance for the new-born calf, because they are absorbed into its circulation system where they fulfill temporarily the immunological functions of blood gamma-globulin. Immunoglobulins (or antibodies) can be absorbed through the intestinal wall only during the first 24 to 36 hours of life, with the maximum amount being absorbed during the first hour. After calving, the concentration of IG in colostrum declines sharply, i.e. from 130 mg/ml of milk at 2 hours to 26 mg/ml of milk at 24 hours. For these reasons, it is of utmost importance that a new-born calf should receive about 5% of its birth weight in colostrum within the first half-hour after birth.

4. Precursors of milk proteins

Casein does not occur in the blood but is synthesised in the udder mainly from the free amino-acids which are absorbed from the blood. Some of the non-essential amino acids are, however, also synthesised in the udder.

The immunoglobulins and certain albumin fractions are identical to the protein of blood. These are transferred directly from the blood to the milk. The other whey proteins are, however, synthesised in the udder.

5. Lactose (milk sugar)

Lactose is found in high concentrations in milk only while very low levels appear also in blood and urine. Lactose is the only carbohydrate in milk. Milk from some mammalian species, such as sea lions and some seals, does not contain any lactose.

Lactose is a disaccharide, being a compound consisting of a molecule each of galactose and glucose. The average percentage of normal cows’ milk generally ranges from 4.6 to 5.2%. This usually amounts to about 50% of the total solids in skim milk.

The osmotic pressure of milk is essentially similar to that of blood and is maintained by the balance of concentration of lactose and soluble mineral matter, mainly chlorides. Thus any variation in lactose concentration is counterbalanced by one in sodium chloride (NaCl) in the opposite direction. The smaller molecular weight of NaCl and its complete dissociation means that a slight increase in chloride concentration is counterbalanced by a much greater decrease in the lactose content of milk.

In a mastitis-infected udder, the permeability of the epithelium cells increases with the result that more blood substances enter the lumen and thus the milk. As the chloride content of blood (about 0.3%) is about three times that of milk, the chloride content of mastitis milk increases from about 0.09 to 0.14%, whereas the lactose content of milk decreases from about 4.9 to 4.6%. Low lactose values in milk samples from individual cows are, therefore, a fair indication of a mastitis infection.

Lactose fulfills an important role in nutrition as it serves as a source of energy providing 4 kCal per gram of milk, while it aids in calcium and phosphorus assimilation and also in the intestinal synthesis of vitamins, e.g. vitamin D in some species.

The primary uses of lactose are the following:
- As an ingredient in infant foods and in special dietary products;
- In the formulation and standardisation of pharmaceuticals, tablets and pills; and
In the production of caramelised dairy products.

Lactose is fermented by bacteria to lactic acid and is therefore of utmost importance in the manufacturing of fermented and ripened dairy products. It also plays an important role in the texture, taste, and solubility of a wide range of dairy products.

The precursor of lactose is blood glucose. Some glucose is converted in the udder to galactose and with both sugars present, lactose is formed.

The contents of the main milk constituents, namely, milk fat, total protein and lactose, are currently determined by means of infra-red analysers. The principle on which these analysers operate is based on the absorption of infra-red light by specific chemical bonds in the milk constituent to be determined.

6. Minerals (milk salts)

The minerals that occur in milk are listed in Table 49.6.

Table 49.6. The mineral content of normal milk

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Content in milk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>0.12</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>0.01</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>0.09</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>0.06</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>0.14</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>0.11</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>0.03</td>
</tr>
<tr>
<td>Citric acid</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.72</strong></td>
</tr>
</tbody>
</table>

Although the mineral content of milk is less than 1%, minerals have a marked effect on the nutritive value, heat, and alcohol stability of milk. Minerals also affect the age, thickening of evaporated and condensed milk, the feathering of cream in coffee, the coagulation of milk by rennet, and the clumping of the fat globules during homogenisation.

Potassium, sodium and chloride are entirely in solution. Phosphate, calcium, magnesium and citric acid are partly in solution and partly in suspended (colloidal) combinations.

In addition to the elements that occur in milk in relatively large proportions, there are a large number of elements usually measured in parts per million (ppm) or micro-grams per ℓ. These are referred to as trace elements (see Table 49.7). The fact that they are present in very small amounts does not detract from their importance since many of these elements are known to have remarkable physiological, catalytic, and nutritional qualities.
It is well-accepted that more trace elements occur in milk. The minerals and their concentration values in Table 49.7 have been selected to give a general indication of their proportions in milk. A higher intake rate of most of these elements should increase their content in milk.

### 7. Vitamins in milk

Milk is a good source of a number of vitamins, such as riboflavin (vitamin B2), while contributing significantly to vitamins A and B1 requirements. Milk has inadequate levels of vitamin C (ascorbic acid) and is a poor source of vitamin D. The most important vitamins in fresh milk are shown in Table 49.8.

#### Table 49.7. The trace element content (microgram/litre, mg/ℓ) of standard milk

<table>
<thead>
<tr>
<th>Elements</th>
<th>Concentration (mg/ℓ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>460</td>
</tr>
<tr>
<td>Arsenic</td>
<td>50</td>
</tr>
<tr>
<td>Boron</td>
<td>270</td>
</tr>
<tr>
<td>Cadmium</td>
<td>26</td>
</tr>
<tr>
<td>Chromium</td>
<td>15</td>
</tr>
<tr>
<td>Copper</td>
<td>130</td>
</tr>
<tr>
<td>Iodine</td>
<td>43</td>
</tr>
<tr>
<td>Iron</td>
<td>450</td>
</tr>
<tr>
<td>Lead</td>
<td>40</td>
</tr>
<tr>
<td>Manganese</td>
<td>22</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>73</td>
</tr>
<tr>
<td>Nickel</td>
<td>27</td>
</tr>
<tr>
<td>Rubidium</td>
<td>2000</td>
</tr>
<tr>
<td>Selenium</td>
<td>40</td>
</tr>
<tr>
<td>Silver</td>
<td>47</td>
</tr>
<tr>
<td>Strontium</td>
<td>171</td>
</tr>
<tr>
<td>Zinc</td>
<td>3900</td>
</tr>
</tbody>
</table>

#### Table 49.8. The most important vitamins in fresh milk

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Content (mg/ℓ)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>136 - 176</td>
<td>• Precursor is carotene which occurs in certain plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Promotes growth and health</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Prevents night blindness and hardening of epithelium tissue (e.g. in the respiratory and reproductive tracts)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Heat stable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Prone to oxidation</td>
</tr>
<tr>
<td>B₁ (Thiamine)</td>
<td>0.02 - 0.08</td>
<td>• Prevents beri-beri</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Partially destroyed by pasteurisation</td>
</tr>
<tr>
<td>B₂ (Riboflavin)</td>
<td>0.08 - 0.26</td>
<td>• Sustains normal growth and skin health</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Destroyed by direct sunlight</td>
</tr>
<tr>
<td>C (Ascorbic acid)</td>
<td>1.57 - 2.75</td>
<td>• Prevents scurvy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Promotes healthy teeth, bones and blood vessels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Destroyed by heat and sunlight</td>
</tr>
</tbody>
</table>
8. Gasses

Milk directly from the udder contains about 8% (by volume) of dissolved gasses. When coming in contact with the atmosphere, the percentage of carbon dioxide (CO$_2$) decreases, while there is a gain in oxygen (O$_2$) and nitrogen (N$_2$). Milk, as delivered to the consumer, contains about 0.5% O$_2$, 1.3% N$_2$, and 4.5% CO$_2$ by volume.

9. Enzymes

Milk contains a number of enzymes as they are components and products of the mammary gland. Certain enzymes can, however, result from bacterial growth in milk. The main enzymes natural to milk include catalase, phosphatase, lipase and reductase:

- **Catalase:**
  
  It decomposes hydrogen peroxide as follows:
  
  \[
  2\text{H}_2\text{O}_2 + \text{catalase} = 2\text{H}_2\text{O} + \text{O}_2
  \]

  Mastitic milk is rich in this enzyme and the release of O$_2$ from H$_2$O$_2$ is used as a diagnostic tool for mastitic milk.

- **Phosphatase:**
  
  The phosphatase enzyme in milk is used in the phosphatase test to determine whether milk has been properly pasteurised. The enzyme is inactivated by heat treatments that are sufficient to destroy pathogenic bacteria such as *Mycobacterium tuberculosis* but that is insufficient to damage the creaming ability of milk, e.g. 72°C for 15 seconds, generally pasteurisation. Any residual activity remaining after pasteurisation and as indicated by the phosphatase test, indicates inadequate pasteurisation.

- **Lipase:**
  
  Lipase plays an important role in milk in that it hydrolyses the triglycerides to set the fatty acids free which result in a rancid taste in milk.

**In closing**

Milk has some distinctive features containing food sources such as fat, protein, lactose, minerals and water. These components vary according to breed. The total solid content of milk is about 13% while the solids-no-fat may be about 9%. The production of milk is a biological process and a considerable number of factors affect the composition of milk. This may result in the composition of milk varying from day to day. The fat in milk consists of a number of fatty acids which have different effects on human health. Because milk has a natural creaming effect, e.g. fat molecules moving upwards in the milk and forming a layer on top of the milk, the way in which milk is sampled for the analysis of its fat, protein and lactose content may affect milk prices. Milk has to be stirred for at least five minutes before milk sampling can be done.
CHAPTER 50

FACTORS AFFECTING THE COMPOSITION OF MILK

Introduction

Milk does not have the same composition at all times because it is a biological product resulting from a number of chemical processes in the udder. The chemical composition of milk also varies because of environmental and physiological factors. In the case of a single cow, the composition of her milk may differ considerably over short periods, e.g. from one milking to another. The extent of the variation of a bulk milk sample would be less when a large number of cows contribute to the sample. Even in large herds the chemical composition of bulk-milk may vary significantly from day to day. The most important factors affecting milk composition are as follows:

1. Breeds and breeding

Milk yield and milk composition are hereditary characteristics and are influenced markedly by breed (Table 50.1).

Table 50.1. The average lactation milk yield and milk composition of all grade and registered dairy cows in milk recording in South Africa for the period 1 March 2006 to 28 February 2007 (4% FCM = fat corrected milk: (0.4 x kg milk) + (15 x kg fat)

<table>
<thead>
<tr>
<th>Breeds</th>
<th>Number of lactations</th>
<th>Milk (kg)</th>
<th>4% FCM (kg)</th>
<th>Fat (%)</th>
<th>Fat (kg)</th>
<th>Protein (%)</th>
<th>Protein (kg)</th>
<th>Protein:Fat ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holstein</td>
<td>60429</td>
<td>8260</td>
<td>7133</td>
<td>3.80</td>
<td>255</td>
<td>3.23</td>
<td>217</td>
<td>0.85</td>
</tr>
<tr>
<td>Jersey</td>
<td>49601</td>
<td>5596</td>
<td>5823</td>
<td>4.68</td>
<td>239</td>
<td>3.75</td>
<td>191</td>
<td>0.80</td>
</tr>
<tr>
<td>Ayrshire</td>
<td>6773</td>
<td>6200</td>
<td>5918</td>
<td>3.95</td>
<td>229</td>
<td>3.33</td>
<td>193</td>
<td>0.84</td>
</tr>
<tr>
<td>Guernsey</td>
<td>1099</td>
<td>5978</td>
<td>5778</td>
<td>4.28</td>
<td>226</td>
<td>3.46</td>
<td>183</td>
<td>0.81</td>
</tr>
</tbody>
</table>

From the data in Table 50.1, it seems that for dairy cow breeds, an increase in milk yield is accompanied by a decrease in fat and protein percentages in milk. Breeds producing less milk have higher fat and protein percentages. Although this increases fat and protein yields, breeds producing a higher volume of milk have higher lactation fat and protein yields.

The fat to protein ratio in the milk of different breeds differ considerably, being 1 : 0.90, 1 : 0.91, 1 : 0.81 and 1 : 0.83 for Friesians, Ayrshires, Guernseys and Jerseys, respectively.

The fat to protein ratio is important with respect to the following:

- It determines the composition of dairy products.
- It is a major factor in determining the producer’s milk price. When the unit price between these two components differs significantly, it may affect breeding strategies.
- In the milk of a single herd, this may indicate diet deficiencies with regards to roughage and energy contents.

Both milk yield and milk composition are hereditary and can thus be affected by breeding and selection programmes. As the heredity of milk characteristics is correlated, a change in the breeding programme may affect all milk traits (Table 50.2).
The stage of lactation has a marked and recognisable effect on both milk yield and milk composition. Milk produced during the first 4 to 5 days after calving is called colostrum, which differs markedly from normal milk. Colostrum contains high levels of most of the milk components except for lactose and potassium. The fat percentage is usually higher, although it may vary considerably. The protein content of milk, especially the albumin and globulin contents, is initially very high, decreasing within a few days back to normal levels (Table 50.4).

### Table 50.2. The genetic correlations between milk traits

<table>
<thead>
<tr>
<th>Traits</th>
<th>Milk (kg)</th>
<th>Fat (kg)</th>
<th>Protein (kg)</th>
<th>Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat (kg)</td>
<td>0.88</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Protein (kg)</td>
<td>0.95</td>
<td>0.93</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>-0.20</td>
<td>0.24</td>
<td>-0.01</td>
<td>-</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>-0.19</td>
<td>0.04</td>
<td>0.06</td>
<td>0.49</td>
</tr>
</tbody>
</table>

From Table 50.2 it seems that the genetic correlation between milk yield and fat and protein yields are highly positive (more than 88%), while on the other hand the correlation between milk yield and fat and protein percentages is negative (about -20%). Therefore, breeding for more milk would increase fat and protein yields, though reducing the fat and protein percentages of milk.

In Table 50.3 the effect of selecting for specific characteristics over a period of 20 years is shown.

### Table 50.3. The milk yield and milk composition as affected by breeding for specific traits over a 20 year period (*Income per lactation based on fat = R7.93/kg and protein = R11.87/kg)*

<table>
<thead>
<tr>
<th>Traits</th>
<th>Milk (kg)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>Income* (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk (kg)</td>
<td>5168</td>
<td>4.3</td>
<td>3.6</td>
<td>3971</td>
</tr>
<tr>
<td>Fat (kg)</td>
<td>4622</td>
<td>4.9</td>
<td>3.8</td>
<td>3881</td>
</tr>
<tr>
<td>Protein (kg)</td>
<td>5126</td>
<td>4.5</td>
<td>3.8</td>
<td>4141</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>3677</td>
<td>5.8</td>
<td>4.0</td>
<td>3437</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>4300</td>
<td>5.4</td>
<td>4.1</td>
<td>3934</td>
</tr>
<tr>
<td>Maximum difference (%)</td>
<td>43</td>
<td>45</td>
<td>14</td>
<td>20</td>
</tr>
</tbody>
</table>

The lactose and ash content of milk are also affected by breed, although to a lesser degree, lactose being 4.87, 4.81, 4.96 and 5.00%, respectively, for Holstein, Ayrshire, Guernsey and Jersey milk. The ash content for these breeds was 0.68, 0.68, 0.74 and 0.70%, respectively.

### 2. Stage of lactation

The stage of lactation has a marked and recognisable effect on both milk yield and composition. Milk produced during the first 4 to 5 days after calving is called colostrum, which differs markedly from normal milk. Colostrum contains high levels of most of the milk components except for lactose and potassium. The fat percentage is usually higher, although it may vary considerably. The protein content of milk, especially the albumin and globulin contents, is initially very high, decreasing within a few days back to normal levels (Table 50.4).

### Table 50.4. The progressive change of colostrum into milk

<table>
<thead>
<tr>
<th>Time after calving</th>
<th>Total solids (%)</th>
<th>Protein (%)</th>
<th>Albumin + globulin (%)</th>
<th>Lactose (%)</th>
<th>Chlorides (%)</th>
<th>Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 h</td>
<td>27.0</td>
<td>17.6</td>
<td>11.3</td>
<td>2.2</td>
<td>0.15</td>
<td>5.1</td>
</tr>
<tr>
<td>6 h</td>
<td>20.5</td>
<td>10.0</td>
<td>6.3</td>
<td>2.7</td>
<td>0.16</td>
<td>6.8</td>
</tr>
<tr>
<td>36 h</td>
<td>12.2</td>
<td>4.0</td>
<td>1.0</td>
<td>4.0</td>
<td>0.16</td>
<td>3.6</td>
</tr>
<tr>
<td>4 days</td>
<td>11.9</td>
<td>3.8</td>
<td>0.8</td>
<td>4.7</td>
<td>0.13</td>
<td>2.8</td>
</tr>
<tr>
<td>7 days</td>
<td>12.1</td>
<td>3.3</td>
<td>0.7</td>
<td>5.0</td>
<td>0.11</td>
<td>3.5</td>
</tr>
</tbody>
</table>
2.1 Milk yield

Following the colostrum period, daily milk yield usually increases sharply to reach peak production at about 4 to 10 weeks after calving. During this period, both the fat and protein percentages of milk decrease reaching minimum levels at about the same time as when maximum daily milk yield is reached. At this stage, the fat percentage of milk may be 0.2 to 0.6 percentage points lower than the fat percentage at the start of the lactation. The decline in protein percentage is usually less than that of fat, also reaching minimum levels at about the same time as maximum milk yield (Figure 50.1).

Figure 50.1. The effect of lactation stage on the milk yield (─), fat (■) and protein (□) percentage of dairy cow milk

Peak milk yield is, among other factors, dependent on the genetic merit for milk yield in dairy cows. It is also affected by body condition at calving, feeding strategy in terms of the late dry and early lactation stages, as well as udder health.

Maximum milk yield usually continues for a few weeks after reaching peak milk yields after which the daily milk yield of cows gradually declines. This decline in milk yield continues until the end of the lactation period and accelerates until after the 30th week of the lactation. A useful approximation is that from peak milk yield, the rate of milk yield decline should not exceed 2 to 2.5% per week.

2.2 Fat percentage

After reaching a minimum level at around peak milk yield, the fat percentage of milk stays relatively constant for a few weeks before gradually starting to increase. This increase continues until the end of the lactation period, when the fat percentage of milk is usually higher than at the start of the lactation period. Cows being milked until very close to calving often show a decline in fat percentage.

The difference between maximum and minimum fat percentages in milk over the lactation period may be about 0.6 percentage points and is often higher in breeds producing milk containing high fat levels. During first lactation, the fat percentage of milk is relatively low at the beginning of the lactation period, while reaching higher levels at the end of the first lactation than in subsequent lactations.

2.3 Protein percentage

The protein percentage of milk is affected by stage of lactation following a similar lactation trend as for milk fat percentage. The variation in protein percentage in milk is, however, less, usually about 0.3%. After the decline in early lactation, a minimum level is reached at the time of peak milk yield or shortly thereafter. Protein percentage then remains fairly constant up to 2 to 5 months after the cow has been inseminated after which protein percentage
continues to increase. This increase in protein percentage during late lactation is often not noticeable in non-pregnant cows.

### 2.4 Lactose percentage

The lactose percentage of milk tends to follow the trend for milk yield. Lactose percentage reaches a maximum level at about the 7th week after calving. After peak, the lactose percentage slowly decreases until mid-lactation, after which the decline becomes more pronounced. The difference between maximum and minimum lactose percentages may be about 0.4% percentage points.

### 2.5 Minerals

The mineral content of milk varies during the lactation period in a similar way as the protein percentage in milk. The calcium and phosphorus contents decrease during the first month of the lactation period, after which it remains relatively constant while increasing during the last three months of the lactation period. During late lactation, the sodium and chloride contents of milk may increase sharply.

### 3. Age of the cow

Cows produce more milk as they get older. The milk yield of mature cows in 4th lactation is about 25% higher than that in first lactation cows. However, with consecutive lactation periods, fat, protein and lactose percentages of cows decrease by about 0.03, 0.01 and 0.04 percentage points, respectively. After 5th lactation, these decreases level off considerably. Due to the higher milk yield in later lactations, the fat and protein yield of older cows also increase (Table 50.5).

The higher milk, fat and protein yields of cows in later lactation are related to an increase in body size (for a higher feed intake) and udder capacity.

<table>
<thead>
<tr>
<th>Lactation number</th>
<th>Milk (kg)</th>
<th>Fat %</th>
<th>Fat kg</th>
<th>Protein %</th>
<th>Protein kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4746</td>
<td>3.61</td>
<td>171</td>
<td>3.24</td>
<td>154</td>
</tr>
<tr>
<td>2</td>
<td>5336</td>
<td>3.56</td>
<td>190</td>
<td>3.24</td>
<td>173</td>
</tr>
<tr>
<td>3+</td>
<td>5802</td>
<td>3.54</td>
<td>205</td>
<td>3.20</td>
<td>186</td>
</tr>
</tbody>
</table>

### 4. Interval between milkings

When the interval between milking sessions is unequal, the milk yield of cows is less after the shorter interval. It is for this reason that the milk yield at the morning milking is higher than the milk yield in the afternoon. The fat percentage in the milk is, however, higher in milk following the shorter interval (Table 50.6).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Preceding milking interval (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Milk (kg)</td>
<td>15.0</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>6.63</td>
</tr>
<tr>
<td>Fat (kg)</td>
<td>1.10</td>
</tr>
<tr>
<td>Solids not fat (kg)</td>
<td>9.43</td>
</tr>
</tbody>
</table>

On a fat-free basis, milking interval has little effect on the protein percentage in milk. When cows are milked twice a day at equal intervals, say at 06:00 and 18:00, the milk yield is usually higher at the morning milking, although at a lower fat percentage.
5. Water intake

Lactating cows require 3 to 5 litres of water for each kg of milk produced. Therefore, restricting the amount and quality of water for dairy cows result in a lower milk yield, as well as fat percentage. Cows having free access to fresh water produce about 7% more milk and 6% more fat than cows having access to water only two to three times per day.

| Table 50.9. The effect of the stage of the milking process on the fat percentage of milk |
|---------------------------------|-----------------|-----------------|-----------------|
| Milk portion                   | Degree of milking | Fat (%) |
| Preceeding milking interval (hrs)| First            | 2nd            | 3rd            |
| 1                       | High            | Low            | Very low       |

6. Mastitis

Udder infection, or mastitis, has a marked and characteristic effect on the milk yield and milk composition of dairy cows (Table 50.7).

Udder infection affects all the major milk components which tend to decrease in concentration, although whey protein, sodium (Na) and Chloride (Cl) show an increase (Table 50.8).

| Table 50.8. The milk composition of cows as affected by mastitis |
|---------------------------------|-----------------|-----------------|-----------------|
| Milk component                 | Effect          | Normal milk (%) | Mastitic milk (%) |
| Fat (%)                        | Decrease        | 3.8             | 3.6             |
| Protein (%)                    | Slight decrease | 3.6             | 3.5             |
| Casein (%)                     | Decrease        | 2.8             | 2.3             |
| Whey protein (%)               | Increase        | 0.8             | 1.2             |
| Lactose (%)                    | Decrease        | 4.9             | 4.4             |
| Sodium (Na⁺)                   | Increase        | 0.05            | 0.08            |
| Chloride (Cl⁻)                 | Increase        | 0.10            | 0.18            |
| Calcium (Ca++)                 | Decrease        | 0.13            | 0.09            |

- The loss in fat yield may be as high as 6 kg/cow/year for each increase of 250 000 cells in somatic cell count above 200 000 cells/ml of milk.
- The lactose content decreased markedly. A lactose content of less than 4.6% in the milk of an individual cow is an indication of mastitis. To maintain the osmotic pressure of milk, the decrease in lactose concentration is countered by an increase in sodium chloride content.
- The total protein content remains relatively constant because the decrease in casein is countered by an increase in the albumin and globulin percentages.
- Mainly due to the decrease in the fat and lactose percentages, the total solids and solids-not-fat content decrease in mastitic milk. A study showed that the total solids concentration was 0.26% lower in mastitic milk (SCC more than 1 x 10⁶/ml of milk) than in normal milk (SCC below 500 000/ml of milk).
- Mastitic milk shows a greater enzyme activity. The catalase activity may be double that of normal milk.

7. Variation in milk composition during a single milking

It is well known that the fat content of milk increases continuously during the milking process, i.e. the fore milk has a very low fat content while stripped milk at the end of the milking process has the highest fat content (Table 50.9). The fat content of the final 5% of milk may be as high as 10%.
Table 50.9. The effect of the stage of the milking process on the fat percentage of milk

<table>
<thead>
<tr>
<th>Milk portion</th>
<th>Proportion of total yield (%)</th>
<th>Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>15</td>
<td>1.9</td>
</tr>
<tr>
<td>Middle</td>
<td>58</td>
<td>2.3</td>
</tr>
<tr>
<td>Last</td>
<td>27</td>
<td>6.8</td>
</tr>
<tr>
<td>Composite</td>
<td>100</td>
<td>3.1</td>
</tr>
</tbody>
</table>

The magnitude of this effect differs greatly among cows, i.e. being more pronounced in high producing cows. From this, it follows that incomplete milking would result in the production of milk containing less fat. When the udder is subsequently milked normally, the fat content of the milk should be higher. When milking is incomplete for several successive days, the fat percentage is markedly less only on the first day of incomplete milking.

The solids-not-fat content, estimated as a proportion of the fat-free milk, does not change during the milking process. Milk yield lost due to incomplete milking, especially in high-producing cows, are normally not fully recovered.

8. Exercise

Excessive exercise has a marked decreasing effect on milk yield. As a result of the lower milk volume, fat percentage increases. The nett result is a slight reduction in fat yield.

Exercise aids in the digestion of feed and coupled with an increased feed intake, milk yield may be maintained, even while the fat percentage increases.

9. Climate

9.1 Season

The seasonal influence on the milk of a single herd is dependent on factors, such as seasonal calving, environmental temperature, and seasonal related feeding strategies.

In South Africa as a whole, milk production is high from September to February and low during the winter months. Fat and protein percentages follow a reverse pattern and are low during the months of high milk production (Figure 50.2).

![Figure 50.2](image)

Figure 50.2. The (a) average daily milk yield (litres x 1 000) and (b) fat (■) and protein (□) percentage of milk as affected by month of the year

9.2 Ambient temperature

Ambient temperature is usually the most important single climatic factor affecting the milk yield of dairy cows. The magnitude of the effect of temperature is dependent on factors, such as breed, air movement, air relative humidity, period of exposure, and individual cows.

The adverse effect of high temperatures is enhanced by long periods of exposure, the absence of air movement, and high humidity.

Milk breeds, which originated in the cold to temperate climate of Europe, are better adapted to low than to high temperatures. The approximate lower and upper critical temperatures for Holstein-Friesian and Jersey cows are shown in Table 50.10.
High ambient temperatures (above 27°C) for short periods, e.g. for only one day, while night temperatures are low, may only have a slight effect on the production performance of dairy cows. Heat stress has a more marked effect on high producing cows, especially during peak production, than on low producing cows.

The influence of high environmental temperatures on the physiology of the cow is given in Table 50.11.

<table>
<thead>
<tr>
<th>Ambient temperature (°C)</th>
<th>Respiration rate (breaths/min)</th>
<th>Rectal temperature (°C)</th>
<th>Hay intake (kg/day)</th>
<th>Milk yield (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>17</td>
<td>38.3</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>21</td>
<td>42</td>
<td>38.3</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>27</td>
<td>56</td>
<td>38.5</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>33</td>
<td>88</td>
<td>39.2</td>
<td>7</td>
<td>11</td>
</tr>
</tbody>
</table>

During cold weather, milk yield and protein percentage may decrease slightly. An increase in fat percentage may occur (Figure 50.3).

These variations are more noticeable when the ambient temperature approaches the critical levels. Wind and a low-energy diet increase the negative effects of low temperatures.

The optimum ambient temperature for dairy cows ranges between 4 and 21°C. As the temperature increases within this range, the fat percentage usually decreases by 0.1 – 0.2% per 6°C. Between 21 and 27°C, the milk yield slowly starts to decrease and the decrease in fat percentage becomes more noticeable.

When the critical temperature is exceeded, milk yield, protein and lactose percentages drop sharply, while the fat percentage usually increases because of the reduction in milk yield.

The detrimental effect of high environmental temperatures may be partly eliminated by measures such as providing shade (Table 50.12), spray cooling and the cooling of the drinking water.

Table 50.10. Critical temperatures for Holstein-Friesian and Jersey cows

<table>
<thead>
<tr>
<th>Breed</th>
<th>Critical temperatures (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Holstein-Friesian</td>
<td>-12</td>
</tr>
<tr>
<td>Jersey</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 50.11. The respiration rate, rectal temperature, hay intake and milk yield as affected by increasing ambient temperatures

Figure 50.3: The effect of ambient temperature on (a) milk yield and (b) milk composition of dairy cows

(a)

(b)
Table 50.12. The effect of providing shade to dairy cows

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Shade provided</th>
<th>No shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature (°C)</td>
<td>28.4</td>
<td>36.7</td>
</tr>
<tr>
<td>Milk yield (kg/day)</td>
<td>16.6</td>
<td>15.0</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Number of mastitis infections</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>Conception rate (%)</td>
<td>79</td>
<td>60</td>
</tr>
</tbody>
</table>

10. Dry period and body condition

The length of the dry period and the body condition of cows at calving are related. Cows must have a dry period of about 60 days to replenish their body supplies and to regenerate secretory tissue in the udder. Cows calving down in a good condition usually produce more milk with higher fat and protein percentages in the following lactation period in comparison to thin (lower body condition score) cows (Table 50.13).

Table 50.13. The effect of the condition score of cows at calving down on the milk yield and milk composition of cows during the first 16 weeks of the lactation period

<table>
<thead>
<tr>
<th>Production parameters</th>
<th>Condition score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Total feed intake (kg DM/day)</td>
<td>16.3</td>
</tr>
<tr>
<td>Peak milk yield (kg/day)</td>
<td>27.8</td>
</tr>
<tr>
<td>Mean milk yield (kg/day)</td>
<td>23.6</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>3.86</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>3.19</td>
</tr>
<tr>
<td>Loss in live weight (kg/day)</td>
<td>-0.04</td>
</tr>
<tr>
<td>Milk yield (kg/lactation)</td>
<td>5 096</td>
</tr>
</tbody>
</table>

In another study, the milk, fat, and protein yield during the first five months of the lactation period increased by 122, 8 and 4 kg, respectively, for each 30 kg increase in live weight during the dry period.

An increase in milk yield is obtained with dry periods of up to approximately 60 days. Increasing the dry periods from 20 to 40 and 40 to 60 days, increases in milk yield of approximately 13 and 3.5%, respectively, can be expected.

11. Season of calving

Particularly in regions where cows are fed a dry ration during winter and go onto green grazing during spring, the season of calving will influence their milk yield per lactation. In the UK, the effect of the so-called spring flush (with regards to the change to pasture feeding), increases the milk yield of cows by 10 to 15%, regardless at which stage of the lactation curve pasture feeding starts. For the spring calving cows, peak production increases followed by a subsequent rapid decline in milk yield. The effect on winter calving cows is most beneficial, because the increase in milk yield then occurs slightly after peak production, which increases and maintains persistency. Cows calving down in autumn experience the spring flush too late in the lactation period to affect milk yield to any extent.

12. Feeding

The effect of feeding on milk production and composition is complicated. A few basic principles apply:

12.1 Composition of ration

A cow, to produce at an optimum level within her genetic potential, needs various nutrients. An ideal ration should contain:

- 16% CP (crude protein),
- 10 – 11 Megajoules (MJ) digestible energy per kg DM,
- 0.6% Ca (calcium),
- 0.4% P (phosphorus), and
- At least 15% CF (crude fibre).

Over and above these guidelines, factors such as protein and fibre quality, mineral and vitamin status should also be taken into account.
12.2 Energy intake

A high energy intake usually results in a higher milk yield and higher protein percentage, but, due to the higher milk yield, fat percentage may decrease.

12.3 Protein intake

Underfeeding protein affects milk yield negatively and may also depress protein percentage during early lactation. By increasing protein intake while maintaining energy levels, the protein percentage in the milk may increase. The response is, however, dependent on the rumen degradability of the protein in the ration. To ensure a high protein percentage in milk, it is advisable that the ration should contain at least 4% non-degradable protein, such as fish meal or oil cake.

12.4 Fat supplements

Including rumen-protected fats in rations usually increases the fat percentage of milk.

The addition of most types of fats and oils to a fat-free or low-fat ration, e.g. to a ration very rich in fibre (1% or less fat), increases the fat percentage of the milk. However, when the level of dietary fat exceeds about 7%, the milk fat percentage, and maybe also the protein content in milk may decrease.

Broadly, it can be accepted that all fats and oils, particularly unsaturated fats such as soya and maize oil, included in rations high in concentrates, decreases butter fat percentage.

12.5 Roughage-to-concentrate ratio

The roughage-to-concentrate ratio in the ration has a distinct effect on the ratio of acetic to propionic acid produced in the rumen.

Acetic acid, the precursor of milk fat, is produced when fibre is digested in the rumen. Propionic acid is derived from the degradation of carbohydrates and promotes the synthesis of lactose, which encourages milk production. Propionic acid serves as an important source of energy during the synthesis of protein by rumen microbes, resulting in higher protein levels in milk. Rations containing high concentrate levels increase the milk yield and protein percentage of cows, while diets high in fibre increases milk fat percentage (Table 50.14).

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Milk yield (kg/day)</th>
<th>Fat (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughage</td>
<td>Concentrate</td>
<td>(%)</td>
</tr>
<tr>
<td>45</td>
<td>55</td>
<td>24.1</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>23.9</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
<td>22.2</td>
</tr>
</tbody>
</table>

12.6 Physical structure and quality of roughage

Finely ground (less than 1.0 - 2.5 cm) and pelleted roughages move through the rumen at a faster rate than long hay. The result of this is that cows ruminate less (chewing the cud) and therefore producing less saliva which normally buffers the rumen resulting in less acetic acid being produced. This may affect the fat percentage in milk negatively. Feeding a small quantity of ungrounded, coarse hay may help to overcome this situation.

Feeding roughages containing high energy levels, such as early-cut silage or hay, increases milk and protein yield, while decreasing fat percentage in milk.

Milk yield, fat and protein percentages may increase when roughage is fed as silage instead of hay. The reason for this is that forage crops are usually harvested earlier for silage than for hay. This increases the energy content of the roughage, while maintaining its fibre content, which is more digestible as it contains less hemi-cellulose and lignin.

12.7 Level of feed intake

The milk yield of cows increases by feeding larger quantities of the same diet, although the fat percentage may decrease. The net result may be a decrease in fat yield.
12.8 Frequency of feeding

When high concentrate rations are fed, the milk fat depression could be overcome by more frequent feeding, i.e. feeding more times per day.

12.9 Feeding of supplements

Milk fat depression as a result of rations low in fibre or in which the roughage is finely ground, may be reduced by feeding pH buffers, such as sodium bicarbonate, magnesium oxide, or sodium bentonite. The optimum level of intake is about 150 to 200 g sodium bicarbonate per cow per day or either 1% sodium bicarbonate or 0.5% magnesium oxide in the concentrate.

13. Milk sampling

For milk analysis, the value of the final results is dependent on the representativeness of the milk sample collected of the total volume of the product to be tested. It is therefore very important that a representative sample for testing is collected. This is very important in the case of milk as creaming takes place when milk is not stirred during storage (Table 50.15).

Table 50.15. The effect of creaming on the fat content in the top 25% of unstirred milk

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Fat content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.25</td>
</tr>
<tr>
<td>½</td>
<td>5.36</td>
</tr>
<tr>
<td>1</td>
<td>6.06</td>
</tr>
<tr>
<td>3</td>
<td>12.00</td>
</tr>
<tr>
<td>5</td>
<td>13.40</td>
</tr>
</tbody>
</table>

The rising fat globules serve as a filter carrying bacteria and somatic cells to the top layers of milk. The latter, upon creaming, will thus also be concentrated in the upper milk layer. Therefore, thorough agitation of milk is required before milk sampling is done to ensure homogeneity. However, agitation of milk should not be excessive to prevent the churning of fat.

When a single sample from several containers is to be compiled, for example, to determine the fat content in the milk of a herd over a 24 h period, a sub-sample of each container should be taken in proportion to the quantity of milk in the specific container. The sub-samples should be combined and, if necessary, mixed and resampled to obtain a suitable sample volume. Factors such as lipolysis (rancidity), churning, and bacteriological deterioration may affect the accuracy of chemical analysis. As these influences are enhanced by temperature, it is advisable to store milk samples prior to analysis at a temperature of below 10°C. To facilitate thorough mixing of a sample before analysis, it is advisable that the bottles should be of a convenient size and not be filled to more than 75% of their capacity.

14. Diagnosing problems with regards to low milk solids content

In Figures 50.4 to 50.6 flow diagrammes are presented to identify possible problems with regards to low fat, protein and lactose percentages in milk. These diagrammes can be used to identify problems quickly.
Figure 50.4. A flow diagramme to determine problems with regards to a low fat percentage in milk
Figure 50.5. A flow diagramme to determine problems with regards to a low protein percentage in milk.
Figure 50.6. A flow diagram to determine problems with regards to a low lactose percentage in milk (SCC = somatic cell count)
CHAPTER 51
MILKING PARLOUR HYGIENE

Hygiene is a way of life

Introduction

Milk, in addition to being a nutritious food source, presents a favourable physical environment for the growth and increase in the number of micro-organisms. Being a metabolic product, it is subjected to widely different production conditions and is normally contaminated by a broad spectrum of micro-organisms. Although bacteria dominate in fresh milk, molds, yeasts, and viruses may also occur.

1. Micro-organisms associated with milk

From the viewpoint of the dairy producer and dairy technologist, it would be sensible to group different bacteria according to the specific changes they bring about in milk and dairy products, or according to their temperature-related characteristics. Important groups, based on these characteristics, are the following:

1.1 Acid-producing bacteria

Acid-producing bacteria ferment lactose mainly into lactic acid. As a result of the acid production, the pH of fresh milk drops from about 6.66 to as low as 4.6. At a pH of about 5.2 and lower, casein in milk coagulates and milk thickens. These bacteria are usually mesophilic, i.e. growing best at moderate temperatures, neither too hot nor too cold, typically between 20 and 45°C. They are the dominant population in milk that has been inadequately cooled. Examples of such bacteria are Streptococcus lactis and Lactobacillus bulgaricus.

1.2 Gas-forming bacteria

These bacteria ferment lactose to produce gas (CO₂ and H₂) in milk and dairy products. Well-known examples include:
- coliform bacteria, e.g. Escherichia coli (E. coli) causing early blowing of cheese, and
- Clostridium butyricum, which is an anaerobic spore-forming bacteria causing late blowing of cheese.

1.3 Sweet curdling and ropiness

Bacteria responsible for these defects in milk are capable of increasing the viscosity of the milk without significant acid production. The responsible bacteria are often contaminants from stagnant water. Examples include the following bacteria:
- Alcaligenes viscosus from stagnant water, and
- Bacillus subtilis from hay and dust.

1.4 Proteolytic bacteria

Proteolytic bacteria decompose the casein in milk, causing faecal odours and bitter flavours. Because of the proteolysis of proteins in milk, it appears to be watery. Example: Clostridium butyricum.

1.5 Psychrotrophic bacteria

Psychrotrophic bacteria are capable of multiplying at temperatures between 2 and 10°C and therefore often become the dominant population in milk that is stored at below 10°C for 2 days or longer. During the first 24 hours’ cold storage, the percentage psychrotrophic bacteria in milk may, for example, increase from 15 to 80% of the total population. Pseudomonas spp., mainly P. fluroescens, usually account for about 50% of the psychrotrophic bacteria in milk and are capable of producing heat resistant enzymes which easily survive pasteurisation.

Due to the proteolytic activity of these enzymes, they are often responsible for the bitter flavours that may develop in pasteurised and sterilised milk.

Off-flavours which may develop in UHT (long-life) milk are often caused by these enzymes.
1.6 Mesophilic bacteria

Mesophilic bacteria can grow at temperatures ranging from 5 to 45°C with an optimum growth temperature of about 25 to 37°C. The majority of bacteria occurring in nature, and thus also in milk, falls within this group.

Example:
- *Streptococci*, e.g. *S. lactis* – lactic acid fermenter,
- *Micrococi*, e.g. *M. pyogenes* – mastitis, and
- *Staphylococcus aureus* – mastitis.

1.7 Thermoduric bacteria

Thermoduric bacteria can survive, but do not grow, at pasteurisation temperatures. Examples of temperature-time combinations for the pasteurisation process are:

- 75°C for 15 seconds, or
- 62.8°C for 30 minutes.

1.8 Spore forming bacteria

Spore forming bacteria are capable of producing endospores (internal) which can survive a heat treatment of 80°C for 10 minutes.

Typical examples are:
- *Bacillus cereus* which causes bitty cream,
- *B. subtilis* which causes ropiness, and
- *Clostridium butyricum* which is responsible for late (butyric) blowing of cheese.

1.9 Coliform organisms

Coliform bacteria have the capacity to produce both gas and acid from lactose at 30°C. The incidence of coliforms in raw milk has received considerable attention due to the following reasons:

- their association with contamination of faecal origin (*Escherichia coli*),
- the off-flavours that they produce in milk, and
- the ease at which their presence can be indicated.

Coliforms readily multiply on moist dairy utensils, especially in the presence of milk residues. Poorly cleansed utensils are often the main source of contamination. *Escherichia coli* (*E. coli*) may be distinguished from the rest of the group due to their ability to produce grass in brilliant green broth at 44°C and indole in tryptone water (Eijkman test). The presence of *E. coli* in water usually indicates recent faecal contamination.

1.10 Total viable count

The total viable or standard plate count indicates the total number of viable microorganisms present in 1 ml of milk as determined by the colony plate count method. The total viable count is often confused with the total count, which is determined microscopically and includes both viable and dead microbial cells. Raw milk sold in South Africa for further processing, is usually classified according to bacterial quality as follows:

- Class A = less than 50 000 bacteria/ml of milk,
- Class B = 50 000 to 200 000/ml of milk, and
- Class C = more than 200 000/ml of milk.

2. The bacterial content of freshly drawn milk

Milk drawn aseptically from a healthy udder usually contains less than 1 000 bacteria/ml of milk. There is a considerable variation in the numbers of organisms found in milk at different stages of the milking process. The foremilk contains the highest number of bacteria, for example, from 1 000 to 10 000/ml. After the first few streams of milk, the count in bacteria decreases sharply and thereafter more gradually until a minimum of 100 to 200/ml is reached in stripped (last) milk. Bacteria present inside a healthy udder are mostly micrococi, which are inactive and do not have a significant influence on the hygienic quality or keeping quality of milk.

Mastitic infected quarters may excrete fluctuating numbers of organisms in their milk. The counts may vary, for example, from a few thousand per ml in milk from sub-clinical cases to more than 10 million/ml in milk from clinically infected quarters. Where bulk milk has a total bacterial count of more than 50 000 bacteria/ml, mastitis is often the reason for the high count.

Milk secreted by infected cows/udders may convey the following pathogens (disease causing) bacteria to the consumer:
• Tuberculoses—Mucobacterium tuberculosis,
• Contagious abortion Brucelloses – Brucella abortus,
• Anthrax – Bacillus anthrax,
• Food poisoning – Staphylococcus aureus (mastitis), and
• Sore throat – Streptococcus pyogenes (mastitis).

3. Sources of contamination

During milk harvesting, bacteria from the external part of the udder, environment, and milking utensils gain entry into the milk. The result is that at the end of the milking process, milk may contain from 10 000 to several hundred thousand bacteria per mℓ of milk.

### Table 51.1. The effect of housing and teat washing on the bacterial content of bulk tank milk

<table>
<thead>
<tr>
<th>Housing</th>
<th>Teats</th>
<th>Bacteria per mℓ of milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedded on sand</td>
<td>Unwashed</td>
<td>31 700</td>
</tr>
<tr>
<td></td>
<td>Washed</td>
<td>15 500</td>
</tr>
<tr>
<td>On pasture</td>
<td>Unwashed</td>
<td>4 250</td>
</tr>
<tr>
<td></td>
<td>Washed</td>
<td>3 530</td>
</tr>
</tbody>
</table>

To minimise contamination from external sources, it is essential to wash the teats thoroughly before milking starts. It is also important to dry teats using a disposable paper towel before attaching the milking clusters.

3.2 Aerial contamination

The number of organisms contaminating milk from the air is normally not high. Bacterial counts on air in milking-sheds should not exceed 200 bacteria per litre. Under normal conditions the levels of contamination from this source are negligible in comparison to that derived from teats, utensils, and surfaces.

Because of the severe conditions existing in the atmosphere, most of the organisms coming from this source are comparatively resistant. They are often responsible for specific defects in milk and dairy products. For this reason, and because the number of micro-organisms in the air is largely dependent on the dust load, pollution of the air with dust, especially immediately before milking, should be kept to a minimum.

Examples:
• Bacillus cereus – bitty cream, and
• Bacillus subtilis – sweet curdling.

3.1 Contamination from the exterior udder and teats

Between milking sessions, udders and teats of cows may become soiled in different ways, e.g. dung, mud, and bedding material. Such dirt may contain many millions of bacteria per gram. If not removed beforehand, the dirt on the teats, together with the large number of bacteria associated with it, may be washed into the milk during milking, resulting in an increase in the bacterial count of the milk accordingly (Table 51.1).

3.3 Water supplies

Water used in the process of milk production should be of bacteriologically potable quality. Using water with a high bacterial load for washing would increase the bacterial count of milk through contamination. Water from storage tanks, boreholes, wells and dams, inadequately protected from rodents, birds and dust, may be contaminated with bacteria from faecal origin. This type of contamination may not only increase the total bacterial count of the milk, but may also be harmful and even pathogenic. Examples of such pathogens include the following:

• Eschericia coli,
• Pseudomonas,
• Faecal streptococci, and
• Bacillus spores.

When water quality is under suspicion, it would be a good practice to delay chemical disinfection of milking equipment until just before the next milking and to merely drain the disinfectant solution from the equipment before milking.
Chlorination, by dosing with hypochlorite, is a common practice to improve the bacteriological quality of water. Chlorinated rinsing water should contain between 1 to 3 parts of active chlorine per million parts of water.

3.4 Milking equipment as a source of bacterial contamination

Inadequately cleansed and disinfected milk contact surfaces are major sources of bacterial contamination of milk. During the usual cleaning process, it is impossible to eliminate all the bacteria on these surfaces. A survey of 350 milking machines showed that in 91% of cases, the total bacterial count on milk contact surfaces was higher than 100 bacteria per cm². For smooth surfaces, such as glass and stainless steel, which are relatively easy to clean, bacterial counts less than 5 bacteria per cm² would be satisfactory. On more porous or coarser surfaces, such as rubber, equipment in poor physical condition, or where milkstone layers occur, the bacterial count may run into many thousands per cm².

The number of bacteria occurring on milk contact surfaces depends, amongst others, on the following factors:

- **The effectiveness of the washing process:** When milk residues, such as fat, protein and minerals, are not completely removed during the washing process, the following may result:
  - large numbers of bacteria surviving in the residues, and
  - protein residues, especially, reacting with sanitising agents, such as chlorine, decreasing the effectiveness of the latter.

Milking equipment should be washed shortly after being used. When milk residues are allowed to dry on contact surfaces, a film, i.e. milkstone, forms. Milkstone consists of protein and milk salts. It is a hard film and difficult to wash off. Milkstone may also form when milk is rinsed from utensils by very hot water.

- **The condition of utensils used:** Corroded or roughened surfaces, milkstone deposits, open seams, etc. not only increase the surface on which bacteria can settle, but also impede effective washing of utensils. Rubber, having an absorbent surface that may become very porous due to maltreatment and corrosion, may, for this reason, be a major source of bacterial contamination. In a study on farms producing milk of unsatisfactory bacteriological quality, it was found that the rubber-ware of the milking machines added 10 to 120 times the number of contaminants normally contributed by the metal and glass parts.

- **Time and conditions under which utensils are stored:** Bacterial growth is largely dependent on temperature and moisture. When utensils are stored under humid conditions, or not properly drained after cleaning, the bacteria that survived the cleaning process may multiply rapidly to large numbers in the interval between milking sessions.

- **Sanitation of utensils immediately prior to use:** The bacteria that survive the initial cleaning process may multiply considerably in the interval between milking sessions. To limit contamination from this source, it is advisable to rinse, immediately prior to use, all milk contact surfaces with a sanitiser. Such sanitisers may be a chlorine solution containing 100 to 150 ppm available chlorine.

Even by rinsing utensils with clean water, depending on the vigor of the rinse, 50% and more of the bacteria may be removed from the utensils.

- **Construction of utensils** Milking equipment is seldom uniformly contaminated. Bacteria and residues accumulate in difficult-to-clean areas and in parts of badly designed components. In any specific milking installation, these problem areas should be identified, regularly inspected, and, if necessary, routinely cleaned by hand. A few examples of trouble areas include the following:
  - all rubber to metal connections,
  - sample cocks at measuring jar outlets,
  - dead-ends in pipes,
  - vacuum to milk line connections,
  - bulk tank outlet taps, and
  - rubber seals such as between lids of containers such as on some measuring jars and milking machine buckets.
3.5 The vacuum line as a source of contamination

In some milking systems, vacuum lines, which are not cleaned during the normal circulation of detergents, open together with milk lines into the same receptacle, for example:

- where the vacuum line, as such or through a pulsator, enters the bucket of a milking system, and
- in most releasers.

Milk residues may enter the vacuum lines through overfilling of containers, cracked inflations, or due to evaporation of warm milk under vacuum and condensation of the moisture in the vacuum system. Bacteria multiplying in these residues may constitute a major source of contamination and for this reason, the vacuum system should be cleaned on a routine basis or whenever milk was sucked into the system.

Table 51.2. The relative importance of the different sources of contamination

<table>
<thead>
<tr>
<th>Source of contamination</th>
<th>Contribution to bacterial count/mℓ of bulk milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal healthy udder</td>
<td>300 to 4 000</td>
</tr>
<tr>
<td>Mastitic udder</td>
<td>Up to 25 000 and more</td>
</tr>
<tr>
<td>External udder</td>
<td>500 to 15 000</td>
</tr>
<tr>
<td>Air (hand-milking)</td>
<td>100 to 1 500</td>
</tr>
<tr>
<td>Milking equipment</td>
<td>Up to 500 000</td>
</tr>
</tbody>
</table>

4. The washing and cleaning of milk utensils

4.1 Types of cleaning agents available

Different types of compounds are formulated to serve a specific purpose in the cleaning process. The best known cleaners available to the dairy industry are:

4.1.1 Detergents

Detergents are formulated to remove organic residues, such as milk fat, protein and mineral deposits. These compounds as such usually have very little, if any, bacterial influence.

Two main types of detergents are available.

4.1.1.1 Alkaline detergents

Alkaline detergents are the oldest and most commonly used dairy cleaner. Normally, they are mixtures of inorganic alkalines, such as:

- Sodium carbonate - Na₂CO₃
- Sodium bicarbonate - NaHCO₃
- Sodium phosphate - Na₃PO₄·12H₂O
- Sodium hydroxide - NaOH

Formulations to improve detergency may include additives, such as wetting agents, water softeners and chlorine. Chlorine is included at a concentration of about 100 ppm available chlorine to assist in the removal of proteins. Due to the low concentration of chlorine, the presence of milk solids, and the high pH of the solution, the bactericidal effect of chlorine may be questionable.

Advantages:
- Dissolves both fat and protein.
- Relatively low corrosiveness.

Disadvantages:
- The continual use of alkaline detergents, especially when used together with hard water, tends to cause a build-up of mineral layers (milkstone). To prevent this, it is advisable to alternatively use an acid detergent once a week.
- Corrosive on aluminum.

4.1.1.2 Acid detergents

Acid detergents usually contain nitric, phosphoric, or sulphamic acid. Their principal function, in a balanced cleaning programme, is to prevent the accumulation of mineral deposits (milkstone).

Advantages:
- Remove or prevent the formation of organic layers.

Disadvantages:
- Acid detergents have little effect on fat and protein containing organic residues.
- Normally more corrosive than alkaline detergents.
4.1.2 Sanitisers

The purpose of sanitisers is to destroy microorganisms. The best sanitisers used in the dairy industry include the following:

4.1.2.1 Chlorine

Active chlorine, especially in a slightly acid medium, is an effective sanitiser. A disadvantage is that it is readily inactivated by organic material, such as fat and protein, and is usually unstable above about 50°C.

When sodium hypochlorite as such is to be used as a sanitiser, it is recommended that the solution temperature should not exceed 50°C and that the concentration should be between 150 to 200 ppm, with the contact time being about 5 to 10 minutes.

4.1.2.2 Iodine

Active iodine solutions are excellent sanitisers, relatively stable in storage and in the presence of organic material. The brown colour serves as an indication of solution strength and the low pH prevents the formation of inorganic layers.

Due to its volatility, the temperature of working solutions should not exceed 50°C.

4.1.2.3 Quaternary ammonium compounds (QAC’s)

These agents are very stable during storage at high temperatures. They are also effective against many types of organisms, non-odorous and non-colouring. Their rinse ability is usually relatively low, which is a decisive disadvantage.

4.1.2.4 Hydrogen peroxide acetic acid

This type of sanitiser has been available since the 1980’s. Bacterial activity is dependent on the presence of peroxy acetic acid and hydrogen peroxide. Characteristics are:

- effective at room (low) temperature (high temperatures will result in the breaking up of the active chemicals and should be avoided),
- kills a broad spectrum of microbes,
- has a fast action,
- effective at a low concentration (0.25 to 0.40%),
- residues, viz. water, oxygen and acetic acid, are non-toxic and do not cause off-flavours in milk,
- long acting, for example, up to 8 hours, and
- at recommended concentrations, it is not corrosive on stainless steel, tin-coated surfaces or aluminium, but may corrode rubber.

4.1.3 Detergent-sanitisers

Detergent-sanitisers are compounds containing both detergents and sanitisers. The advantage of such a compound is that the cleaning operation is simplified. The disadvantage is that the effectiveness of the sanitiser being applied in the presence of milk residues is usually impaired.

Examples of this type of compound are:

- Chlorine containing alkaline detergents. In this case the chlorine content of the working solution is about 200 ppm.
- Iodofors. Iodine together with a wetting agent. Iodofors usually contain phosphoric acid.
- Quaternary ammonium compounds are in themselves good wetting agents and therefore have a built-in detergency.

Cleansing agents, especially alkaline detergents, are available in powdered, as well as in liquid form. Foaming and non-foaming formulations are also available for manual and circulation cleaning respectively.

5. Cleaning procedures

The cleaning process has as purpose:

- to remove organic and inorganic residues, and
- to destroy as many of the remaining bacteria as practically as possible.

5.1 Five-stage system

The traditional procedure for the cleaning of the dairy utensils, both in manual or circulation-in-place (CIP) systems, consists of the following five stages:

- Pre-rinse
  The function of the pre-rinse, which is done with water at a temperature not exceeding 45°C, is to remove as much of the milk residues as possible. In CIP systems, rinsing water is not circulated but run to waste until free of milkiness.
To prevent the formation of a film of milk solids which, at a later stage, will be difficult to remove, pre-rinsing should be done as soon as possible after utensils have been used. Hot water is not recommended for pre-rinsing as it encourages the formation of milkstone.

• Wash
The purpose of the washing process is to remove all remaining residues. Wash with a hot (60 to 80°C) alkaline detergent solution. Solution strength is usually about 0.5% and the minimum circulation time in CIP systems, about 10 minutes. For manual washing, the temperature should be above 40°C. To prevent the build-up of milkstone, the alkaline detergent has to be alternated, say once a week, with an acid detergent.

• Intermediate rinse
Clean water is used to remove the soiled detergent wash. The rinsing allows the sanitiser to act on surfaces free of organic residues.

• Sanitising
Circulate a sanitiser solution containing, for example 150 to 200 ppm active chlorine, for at least 5 minutes.

By separating the cleaning and sanitising processes, the sanitiser can be used at its optimum pH for a minimum contact time and at a lower concentration. This reduces the risk of corrosion, as well as costs.

• Final rinse
The last step in the cleaning process is to get rid of the residues of cleaning compounds, which may tint the milk or corrode the utensils. Water of good bacteriological quality, such as chlorinated water containing 1 to 3 ppm chlorine, is used for the final rinsing.

Alternative
Instead of sanitising immediately after washing, the sanitiser may also be applied just before the utensils are used. This assures a low number of bacteria on the equipment and prevents the corrosion of stainless steel, which can occur if certain sanitisers are in contact with the metal for a long period of time.

5.2 Three-stage system
By developing detergent-sanitisers, it became possible to combine the cleaning and sterilising processes. This has led to the well-known three stage method, which consists of the following stages:

• pre-rinse,
• circulate hot detergent-sanitiser solution, and
• final rinse.

In both the 3- and 5-stage cleaning procedures, an acid detergent, at about one tenth of the normal concentration, can be used to acidify the final rinsing water. By reducing the pH of the rinsing water to less than 4.5, the build-up of milkstone and the multiplication of bacteria is largely prevented.

5.3 Acidified boiling water (ABW) system
This system was developed for the cleaning of pipeline milking machines and consists of only two stages:

• pre-rinse to remove milk residues, and
• the flushing of the pipelines with water, at a temperature of 90°C or higher, which contains about 0.5% sulphamic or nitric acid.

This method of cleaning can be very effective, but requires considerable supervision. All inner plant surfaces must come in contact with the diluted acid and a temperature of at least 77°C must be maintained within the cleaning circuit for at least 2 minutes. Examples of cleaning programmes for milking machines are presented in Table 51.3.
### Table 51.3. Examples of cleaning programmes for milking machines

<table>
<thead>
<tr>
<th>Actions</th>
<th>Programmes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pre-rinse with water at ≤ 40 °C</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Wash with ± 0.5% warm (60 - 80 °C) alkaline detergent</td>
<td>Yes</td>
</tr>
<tr>
<td>3. Rinse with water</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Sanitize with 150 ppm chlorine, 25 ppm iodine or 0.25% H₂O₂/Hac, preferably before being used</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Rinse with clean water</td>
<td>Yes</td>
</tr>
<tr>
<td>6. Rinse with ± 0.15% acidified water with a pH of &lt; 4.5</td>
<td>Yes</td>
</tr>
<tr>
<td>7. Periodically remove milkstone with 0.3 to 1% acid detergent</td>
<td>Yes</td>
</tr>
<tr>
<td>8. Wash without circulation using 0.55% acidified water at ≥ 90 °C</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### 5.4 Cleaning of bulk tank

When the bulk tank is not cleaned by means of a CIP system, the following procedure is recommended:

- Rinse with tap water.
- Prepare, in a plastic bucket, a chlorinated, foaming alkaline detergent at 7 - 10 times the normal strength. Close tank outlet, place bucket containing the detergent inside the tank and thoroughly brush all inside surfaces from the bucket. Let detergent flow from the tank to the bucket. Dismantle outlet tap and wash brush in the bucket. Use detergent from bucket to wash the outside of the tank.
- Rinse inside and outside with tap water.
- Rinse inside with acidified water (acid detergent) at about 10% normal concentration.
- Sanitise before use.

### 5.5 Cleaning the vacuum line

- Draw hot alkaline detergent through each stall cock into the vacuum line. Start at the cock nearest the vacuum pump. Do not draw more solution into the system than the moisture trap can hold.
- Drain detergent from moisture trap.
- Repeat with hot acid detergent, starting at the cock farthest from the pump. Drain trap.
- Rinse with clean water, starting at the cock farthest from the pump. Drain trap.
- Open all stall cocks and run the pump to dry the vacuum line.

### 6. Factors affecting the success of a cleaning programme

The following factors have a decisive effect on the effectiveness of a cleaning programme.

#### 6.1 Quality of the water

The most important characteristics that determine the quality of the water are the hardness, the bacteriological quality, and the iron and manganese content.

Water hardness is measured by the content of calcium carbonate equivalent in mg/litre (Table 51.4).

### Table 51.4. Classification of water hardness

<table>
<thead>
<tr>
<th>Hardness</th>
<th>CaCO₃ equivalent mg/ℓ of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>0 to 60</td>
</tr>
<tr>
<td>Moderate</td>
<td>60 to 120</td>
</tr>
<tr>
<td>Hard</td>
<td>120 to 180</td>
</tr>
<tr>
<td>Very hard</td>
<td>Over 180</td>
</tr>
</tbody>
</table>
The water softening ability of well-formulated detergents is usually sufficient for moderately hard water. If the hardness is more than 150 mg/l, it is recommended that the detergent concentration should be increased by 10% for each increase of about 50 mg CaCO₃/l. For very hard water, special formulations may be required.

Iron and manganese present in concentrations of 0.1 ppm or higher, may, especially in the presence of alkaline detergents, be responsible for a build-up of brown-red or black layers. To prevent this build-up, acid detergents should be used more often in the cleaning programme.

When the water used for the washing of udders or the rinsing of the milking utensils contains large numbers of bacteria, it will have a detrimental effect on the quality of the milk. Water of good bacteriological quality should comply with the standards indicated in Table 51.5.

### Table 51.5. The bacteriological standards for water used for washing of udders and rinsing of milking utensils

<table>
<thead>
<tr>
<th>Criterium</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total viable count 21 °C/72 h</td>
<td>&lt; 500/ml</td>
</tr>
<tr>
<td>Total viable count 37 °C/72 h</td>
<td>&lt; 50/ml</td>
</tr>
<tr>
<td>Coliforms</td>
<td>&lt; 50/100ml</td>
</tr>
<tr>
<td>E.coli</td>
<td>Negative/100ml</td>
</tr>
</tbody>
</table>

#### 6.2 Choice of cleaning compounds and procedure

Cleaning compounds are formulated for a specific purpose (see 4.1) and should be applied accordingly in an effective programme (see 5).

#### 6.3 Concentration of the cleaning compound

Both economy and the effectiveness of the compound are influenced by its concentration. The recommended concentration is usually the optimum and should be adhered to. Cleaning agents, especially those containing chlorine, may lose strength during the storage; therefore, it is important to limit the storage time while keeping containers well closed and in a dry area.

When the water is very hard or the temperature is low, then the concentration of the detergent should be increased.

#### 6.4 Temperature of detergents

The effectiveness (detergency) of any detergent is largely dependent on the temperature of the washing water. Usually, the detergency of washing water is better when the temperature of the water is higher. For circulation cleaning of milking machines, the initial temperature of the detergent should be about 75 to 80°C (Table 51.6). At the end of the circulation time, it should preferably not be below 45°C.

### Table 51.6. The total viable count on milking machine rinsings

<table>
<thead>
<tr>
<th>Initial temperature of detergent (°C)</th>
<th>Distribution of bacteria/0.1m² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less than 10 000</td>
</tr>
<tr>
<td>82</td>
<td>50.2</td>
</tr>
<tr>
<td>45 to 60</td>
<td>20.0</td>
</tr>
<tr>
<td>45</td>
<td>14.3</td>
</tr>
</tbody>
</table>
6.5 Volume of detergent and circulation speed

The volume must be sufficient to wet all milk contact surfaces. For milking machines with weighing bottles, approximately 8 to 14 litres of solution is required per milking point.

For the thorough removal of residues, a flow speed of not less than 3.5 litres/minute/milk point must be maintained.

6.6 Circulation time

Due to the decrease in solution temperature, an extended circulation time may be counter-productive. Circulation for 10 to 15 minutes should be sufficient. The temperature at the end of the washing cycle should preferably not be less than 45°C.

6.7 Supervision

An important reason why cleaning programmes fail is because of the lack of supervision. If the operator adheres to the abovementioned details, success, even using a simple procedure, is obtainable.

7. Cooling and milk quality

The bacteria present in milk at the end of the milking process multiply quickly during storage at room temperature. As the generation time of bacteria is strongly affected by temperature, prompt cooling to a low temperature delays the increase in the number of bacteria in milk. The effect of cooling is, however, dependent on:

- storage temperature,
- rate of cooling,
- storage time, and
- initial bacterial count.

7.1 Storage temperature and time

The generation time, i.e. the time necessary for a single bacterium to divide into two cells, is largely dependent on temperature. A generation time of 30 minutes at 35°C may for example increase to 11 hours at 5°C. The effect of storage temperature and time on bacterial counts on the bacterial count in milk is presented in Table 51.7.

<table>
<thead>
<tr>
<th>Storage temperature (°C)</th>
<th>Bacterial count after storage for days</th>
<th>Increase %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>160 000</td>
<td>430 000</td>
</tr>
<tr>
<td>7</td>
<td>160 000</td>
<td>3 400 000</td>
</tr>
<tr>
<td>10</td>
<td>160 000</td>
<td>69 000 000</td>
</tr>
</tbody>
</table>

Table 51.7. The increase of bacterial counts as affected by storage temperature and time

7.2 Initial count

The generation time at a specific temperature is significantly affected by the initial bacterial count (Table 51.8). At a storage temperature of 5°C, the bacterial count of fresh milk may increase by 25% after 24h, however, when the bacterial count in fresh milk is higher, the increase in bacterial count is much higher, e.g. 180%. At a higher storage temperature, the increase in bacterial count is even higher, e.g. 250 and 780%. These increases in bacterial count in milk would have a major effect on the quality of milk following its initial bacterial count and storage temperature.

<table>
<thead>
<tr>
<th>Storage temperature (°C)</th>
<th>Bacterial count</th>
<th>Increase %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh</td>
<td>After 24 h</td>
</tr>
<tr>
<td>5</td>
<td>4 000</td>
<td>5 000</td>
</tr>
<tr>
<td></td>
<td>136 000</td>
<td>381 000</td>
</tr>
<tr>
<td>10</td>
<td>4 000</td>
<td>14 000</td>
</tr>
<tr>
<td></td>
<td>136 000</td>
<td>1.2 x 10⁶</td>
</tr>
</tbody>
</table>

Table 51.8. The rate of bacterial growth during storage as affected by initial count
In closing

Milk, being a food source, is an ideal medium for the growth of micro-organisms. It naturally contains a broad spectrum of such organisms which multiply under specific environmental conditions. Milk contains acid-producing bacteria which naturally ferments lactose in milk to lactic acid increasing the acidity levels in milk as indicated by a decrease in the pH level of milk. At a pH below 5.2, the casein component in milk coagulates and milk thickens. Mastitis is a major problem in dairy cows as mastitic milk contains large numbers of different bacteria which reduces the feeding value of milk. During milking, or milk harvesting, bacteria from the external part of the udder, environment, and milking utensils gain entry into the milk. Therefore, the milking process, the operation and maintenance of the milking machine as well as the environment cows are housed, have a major effect on the occurrence of mastitis in cows and the quality of milk.
CHAPTER 52

MASTITIS AND MILK QUALITY

Introduction

The quality of milk is described by the solids content consisting of fat, protein and lactose percentages, as well as the somatic cell count (SCC) in milk. The SCC of milk refers to the number of white blood cells and the number of epithelial cells in milk, usually per mℓ of milk. The SCC is used as an indication of the level of infection in the udder and is regarded as an indirect way of describing the level of mastitis in milk. When an infection occurs in the udder, the body produces a large number of white blood cells to resist the infection. Because of the increasing number of white blood cells, especially neutrophils, the SCC count in milk increases above the standard level in milk. Udder infection or mastitis is the single most important reason for an increasing number of white blood cells. For this reason, an increase in the SCC of milk is the most reliable and practical way to identify sub-clinical mastitis in the udder of dairy cows.

The SCC in milk from a healthy udder is usually below 200 000 per mℓ of milk. A positive indication of udder infection (mastitis) is usually when the SCC in milk has increased to about 400 000 per mℓ of milk. As mastitis may occur in only one of the four quarters, the SCC of a single milk sample from all quarters must be evaluated carefully, especially when setting threshold values for SCC (Table 52.1).

Table 52.1. The percentage correct and incorrect mastitis classifications when using different mathematical estimations of threshold values for somatic cell count (SCC) for individual cows

<table>
<thead>
<tr>
<th>Threshold value (SCC/mℓ of milk)</th>
<th>100 000</th>
<th>200 000</th>
<th>300 000</th>
<th>400 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>44</td>
<td>69</td>
<td>78</td>
<td>84</td>
</tr>
<tr>
<td>False negative</td>
<td>0.3</td>
<td>2.0</td>
<td>5.1</td>
<td>9.1</td>
</tr>
<tr>
<td>False positive</td>
<td>55.9</td>
<td>29.1</td>
<td>16.9</td>
<td>6.8</td>
</tr>
</tbody>
</table>

In dairy herds already applying the correct mastitis control measures, individual cow SCC may be used as an additional source of information with regards to the mastitis status of the herd. Possible advantages emanating from regular testing for mastitis may be as follows:

- An indication of the number of cows to be culled because of chronic infections not responding to the treatment of mastitis.
- An indication of early drying-off cows with the aim of treating an infected quarter while the cow is dry.
- An early indication of infections which may then be treated or to conduct bacteriological culturing towards identifying specific bacteria that may respond differently to treatment.
- By grouping records according to lactation stage, age of cows, etc. valuable deductions could be made regarding the following:
  1. The number of mastitis cases in the herd,
  2. The number of mastitis cases among first lactation cows,
  3. The lactation stage when udder infections occur, and
  4. The effect of herd management on the incidence of mastitis.

When individual SCC numbers are being used to determine when and which cows to cull, dry off, and to treat cows, this may result in preventive measures being disregarded. This may result in an increase in the number of mastitis cases in the herd. The axiom ‘prevention is better than cure’ applies especially with regards to mastitis management.

Herd somatic cell count (HSCC)

Herd SCC is generally used as a suitable indicator of the udder health in a dairy herd (Table 52.2).
It must be kept in mind that a high HSCC may be the result of high proportion of subclinical mastitis cases (infected quarters) or a smaller proportion of clinical cases of mastitis. With regards to clinical cases, the SCC in individual quarters may be higher than 10 million per mℓ of milk. In a small herd, a single or a few cases of clinical mastitis may affect the herd SCC very strongly.

The HSCC of milk samples collected monthly from about 1650 dairy farmers in the Western Cape during a 12-month period is presented in Table 52.3.

### Table 52.3. The distribution of herd somatic cell counts (HSCC) for dairy farmers in the Western Cape over a 12-month period

<table>
<thead>
<tr>
<th>HSCC (x 1000/mℓ milk)</th>
<th>Proportion of milk samples (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 99</td>
<td>2.2</td>
</tr>
<tr>
<td>100 – 199</td>
<td>12.7</td>
</tr>
<tr>
<td>200 – 299</td>
<td>20.1</td>
</tr>
<tr>
<td>300 – 399</td>
<td>18.2</td>
</tr>
<tr>
<td>400 – 499</td>
<td>13.8</td>
</tr>
<tr>
<td>500 – 699</td>
<td>16.5</td>
</tr>
<tr>
<td>700 – 999</td>
<td>10.4</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>6.1</td>
</tr>
</tbody>
</table>

### Economic implications of a high herd somatic cell counts

It is well-known that mastitis not only affects the appearance and composition of milk, it also results in a reduction in milk yield. Although the reduction in milk yield may not always be noticeable, it may be responsible for up to 80% of the total cost of mastitis. The relationship between HSCC and a reduction in milk yield varies among studies. A realistic relationship between HSCC, the percentage milk yield loss, the amount of milk and potential income lost annually is presented in Table 52.4.

### Table 52.4. Milk and financial losses because of mastitis as reflected by herd somatic cell counts (HSCC)

<table>
<thead>
<tr>
<th>HSCC</th>
<th>Milk yield loss (%)</th>
<th>Monthly loss depending on daily milk yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>600 ℓ</td>
</tr>
<tr>
<td>250 000</td>
<td>3</td>
<td>540 ℓ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R326</td>
</tr>
<tr>
<td>500 000</td>
<td>6</td>
<td>1 095 ℓ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R876</td>
</tr>
<tr>
<td>1 000 000</td>
<td>10</td>
<td>1 825 ℓ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1 460</td>
</tr>
</tbody>
</table>
Based on another study, the following equation was developed to estimate the reduction in milk yield because of mastitis:

\[
\text{Milk yield loss (\%) } = 2.39 + 0.01(\text{HSCC}/1000)
\]

This means that for herd somatic cell counts of 250 000, 500 000 and 1 000 000, milk yield losses are estimated to be 4.9, 7.4 and 12.4%, respectively.

### Table 52.5. The effect of mastitis on milk composition

<table>
<thead>
<tr>
<th>Milk component</th>
<th>Effect</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal milk</td>
</tr>
<tr>
<td>Fat percentage</td>
<td>Reduction</td>
<td>3.8</td>
</tr>
<tr>
<td>Protein percentage</td>
<td>Small reduction</td>
<td>3.6</td>
</tr>
<tr>
<td>Casein percentage</td>
<td>Reduction</td>
<td>2.8</td>
</tr>
<tr>
<td>Whey protein percentage</td>
<td>Increase</td>
<td>0.8</td>
</tr>
<tr>
<td>Lactose percentage</td>
<td>Reduction</td>
<td>4.9</td>
</tr>
<tr>
<td>Na⁺</td>
<td>Increase</td>
<td>0.05</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>Increase</td>
<td>0.10</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>Reduction</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Some of the changes in the chemical composition of milk, as indicated in Table 52.5, reduce the quality of dairy products that are produced from mastitic milk. Examples include a reduction in the curdling of milk and cheese, milk powder dissolving poorly, and sedimentation occurring in ultra-high temperature (UHT) milk.

### Mastitis prevention

A strategy to reduce the incidence of mastitis in a dairy herd should include the following principles:

1. Treating infected quarters; although this is part of the mastitis prevention strategy, it only treats the symptoms, and not the causes, of mastitis.
2. The prevention of mastitis does not rely on some superior medicine and quick fixes, but largely on a continuing evaluation and adaptation of mastitis control measures.
3. A case of mastitis can only occur after a pathogen has entered the udder through the teat opening. The aim of mastitis management should be to reduce the possibility of such an event. For this reason, injuries to the teat opening should be prevented, while the exposure of the teat opening to pathogens should be reduced.
4. Aiming to maintain a realistic standard of mastitis infection in the herd should be part of a mastitis control system. Examples of such a goal should include the following:
   - A mean monthly HSCC of less than 300 000 per ml of milk.
   - A maximum of 35 clinical infected quarters per 100 cows per year, \((35/ (100*4)) = 8.75\%\).
   - 90% of cows should have SCC less than 400 000 per ml of milk.

A mastitis control programme should include the following principles:

1. **A correct milking procedure, e.g.**

   - Not wetting the udder excessively,
   - Drying teats and udder properly,
   - Ensuring that a proper milk let-down process occurs,
   - Test regularly for mastitis before milking by using the strip cup,
   - Keeping record of positive quarters (mastitis can be transferred by milkers by hand between cows),
   - Attach milking clusters correctly, not too soon or too long after stimulation,
   - Prevent over-milking in cows,
   - Rinse milking clusters between successive cows,
   - Milk cows with infected quarters at the end of the milking process, which is especially important for *Staphylococcus aureus* and *Streptococcus agalactiae* infections, and
   - Applying teat dip after milking.
2. A correct milk machine operation, sanitising and maintenance, e.g.:

- Prevent air leakages between teat and milk cluster during the milking process,
- Cut vacuum before attempting to remove the cluster unit from the udder,
- Efficient milking machine functioning involves the following:
  - Regular servicing and testing of the milking machine,
  - Maintaining the correct vacuum levels (50 kPa),
  - Maintaining a stable vacuum level in the cluster which depends on sufficient vacuum reserve levels \((100 + 25 \times n)\) where \(n = <10\), sufficient capacity of the cluster, air flow holes in the milking cluster are open, a short milking tube between cluster and milk line (not longer than 1.5 m), and low milk lines.
- A correct pulsation rate \((60 \pm 5\) per min), and
- The correct pulsation ratio \((D\text{-value} = >15\%\).

3. Acceptable treatment strategies:

- Establish a strategy with regards to the treatment of mastitis cases during the lactation period and at the end of the lactation period, at drying off. Dry cow treatment should either be for all cows or only for specific cows. The correct treatment of mastitis in lactating cows involves treating cows early using a suitable antibiotic while maintaining the treatment until the infection is cleared up.
- Using a specific antibiotic treatment should be motivated.
- Keep records of treatments and the success rate of treatment.
- Where possible, bacteriological culturing should be done to identify bacteria for a specific treatment.
- Keeping a realistic cull rate of cows suffering from recurring incidences of mastitis.

4. Managing the environment:

Provide a friendly, hygienic and dry environment for cows in the herd. This specifically refers to:
- Calving down areas,
- Holding areas before and after milking,
- Passage ways at feeding troughs and lanes to and from the milking parlour,
- Avoid wet, saturated pastures, provide good drainage,
- Provide correctly designed and built free stalls for cows to lie down in housing systems. This specifically refers to the length, width of free stalls, free stall surfaces areas (avoid using saw dust as bedding), well ventilated buildings and high roofs to reduce heat stress,
- Control flies by removing manure and keeping soil surfaces dry,
- Provide hygienic and a dry area for dry cows, and
- Maintain a correct feeding programme with regards to minerals and vitamins, specifically shortages in selenium and vitamin E may have a negative effect on udder health.

Know the enemy

Knowing the specific pathogen causing mastitis in dairy herd may go a long way in reducing the herd somatic cell count. For this reason, it is important that mastitic milk should be regularly cultured to identify pathogen causing mastitis. A sterile milk sample from an infected quarter should be collected for culturing at a suitable facility for identifying specific bacteria. A summary of the most important mastitis-causing bacteria is presented in Table 52.6.
Table 52.6. The most important mastitis causing bacteria affecting dairy cows

<table>
<thead>
<tr>
<th>Pathogens</th>
<th>Source of contamination</th>
<th>Control measures</th>
</tr>
</thead>
</table>
| **Staphylococcus aureus** | • Infected quarters  
• Open wounds on teats  
• Damaged teat openings  
• Skin of the teats and the udder | • Maintain a functional milking machine  
• Prevent injuries to teats and cross contamination  
• Maintain a high milking parlour hygiene  
• Apply teat dip after milking  
• Apply a correct dry cow treatment  
• Cull chronic cases of S. aureus infection  
• Treatment during the lactation period is often unsuccessful (less than 40%) |
| **Streptococcus agalactiae** | • Infected quarter | • Maintain a functional milking machine  
• Prevent cross contamination  
• Maintain a high milking parlour hygiene  
• Apply teat dip after milking  
• Apply a correct dry cow treatment  
• May be successfully treated during the lactation period (75%) |

2. Pathogens from the environment

| **Streptococcus uberis** | Occur on a wide spread basis e.g.  
• in the housing environment,  
• on the skin surface of cows,  
• infected quarters, wet udders and  
• teat washing cloths | • Maintain a high milking parlour hygiene  
• Wash and dry teats before milking  
• Provide a clean and dry housing environment  
• Consider applying a pre-milking teat dip  
• Treatment during the lactation period and the dry period is often successful |

| Different coli-form bacteria such as:  
*Escherichia coli*  
*Klebsiella spp.*  
*Enterobacter spp.* | • Manure,  
• Dirty, wet and muddy soil surfaces  
• Infected water  
• Dirty milking equipment  
• Bedding material such as saw dust | • Provide a clean and dry housing environment  
• Maintain a high standard of hygiene in free stalls  
• Keep teats and the udder dry and clean  
• Apply a dry cow treatment  
• A post-milking teat dip is not very efficient for these pathogens |

It is well known that a wide range of factors, separately and complementary, may contribute to the occurrence of mastitis in a dairy herd. Because of the relative importance of the individual factors that may differ between herds, each factor’s contribution is difficult to quantify. The following summary (Table 52.7) provides an indication of the most probable effect of some of the factors causing new cases of mastitis.

Table 52.7. The most probable effect of different factors on mastitis

<table>
<thead>
<tr>
<th>Factors</th>
<th>Most probable effect on mastitis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teat dip</td>
<td>50 – 70% less</td>
</tr>
<tr>
<td>Milking cluster</td>
<td>About 20% less</td>
</tr>
<tr>
<td>Screens in short milking tube</td>
<td>About 15% less</td>
</tr>
<tr>
<td>Clusters slipping off</td>
<td>Significantly more</td>
</tr>
<tr>
<td>Changes in vacuum during milking</td>
<td>Little to significantly more</td>
</tr>
<tr>
<td>High vacuum levels</td>
<td>Mostly more</td>
</tr>
<tr>
<td>Rinsing of clusters between cows</td>
<td>Relative little value</td>
</tr>
<tr>
<td>Incorrect pulsation</td>
<td>Increases</td>
</tr>
<tr>
<td>Incorrect cluster removal</td>
<td>Increases</td>
</tr>
<tr>
<td>Over-milking</td>
<td>Uncertain to probably</td>
</tr>
<tr>
<td>Incomplete milking</td>
<td>Varying response</td>
</tr>
<tr>
<td>Separating infected cows</td>
<td>Result in fewer cases</td>
</tr>
<tr>
<td>Pre-milk teat dipping</td>
<td>No to little effect</td>
</tr>
</tbody>
</table>
From this it seems that some factors require more emphasis than others, e.g. teat dipping after milking is more important than pre-milking. Similarly rinsing clusters between cows seem to have relative value as the water quality may be questionable. High vacuum levels mostly increase the probability of mastitis.

**In closing**

The fat, protein and lactose contents as well as the SCC of milk indicate the quality of milk. The SCC is used as an indication of the number of white blood cells and epithelial cells in milk which is an indirect indication of the mastitis infection in milk. This is because when some infection occurs in the alveoli, the body produces white blood cells to combat the infection. Increasing the number of white blood cells causes the SCC count in milk to increase above the standard level in milk. Udder infection or mastitis is the single most important reason for an increasing number of white blood cells. For this reason, an increase in the SCC of milk is the most reliable and practical way to identify sub-clinical mastitis in the udder of dairy cows. A wide range of factors, separately and complementary, contribute to the amount of mastitis cases in a dairy herd. The relative importance of individual factors differs between herds. Factors affecting mastitis include the following: a correct milking procedure, a correct milking machine operation using correct sanitising and maintenance procedures, correct treatment strategies and providing a clean and hygienic environment for cows.
CHAPTER 53
MILKING PARLOURS FOR MODERN DAIRIES

Introduction

Like most businesses, dairy farming has to be profitable. Part of the financial success is the consumer demand for the dairy farm’s products, namely, milk and beef. Dairy farms require a large capital outlay which consists mostly of cows, feeds, heavy equipment like tractors, trucks, feed mixing equipment, and various buildings. This includes the milking machine, bulk tanks, milking parlour and associated structures, such as holding areas, feeding silos, crushes, a scale for weighing cows, etc. Cows are usually milked at least twice a day for every day of the year. As the labour input of milking cows is a major factor, it is of utmost importance that the milking parlour is suitable for the operation. This is mainly determined by the number of cows being milked every day. Milking cows must be an easy operation as this is mostly reliant on people doing the physical work. The labour force milking cows each day has a major effect on the quality of milk recovered from cows before being processed, as well as the survival or longevity of cows.

This is why it is important that the harvesting of milk, being the most important income on a dairy farm, is done professionally and correctly. This must be done with the greatest care without affecting the welfare of cows, as this may have a large negative effect on their longevity and the eventual financial sustainability of the farm. The genetic level of the herd and the quality of feed being used on a daily basis are important factors affecting the total milk output of the herd. However, the milking process is a major factor in extracting the milk from cows, as this is the major product that is produced on a dairy farm.

A milking parlour on a dairy farm is a specialised building, or section of a building, designed to milk cows and handle milk. The milking parlour must be designed, constructed and managed with the goal of providing a safe and enabling environment for cows and workers. The milking system and its operation must ensure a continuous daily collection and storage of high quality milk. A well-designed milking centre should allow cows, milk, and waste water to be handled effectively and efficiently. Decisions concerning the milking centre are some of the most complicated decisions a dairy farmer has to make. Milking procedures, herd size, expansion plans, milking interval, and the equity position of a producer influence these decisions. One specific milking parlour would not meet the requirements of all dairy farmers.

Past milking systems

Looking at the world production and herd size figures, one can see that average herd size has increased dramatically, with the number of dairy farms decreasing in proportion. In South Africa, the average herd size, in the late 1990s, was 90 lactating cows. Currently, this figure is estimated to be about 130 to 200 lactating cows with the number of large herds (in excess of 500 cows) increasing. This means that the management on dairy farms is getting more and more important, and many crucial decisions have to be made every day on the farm.

Which milking system to use?

Dairy farmers wishing to upgrade existing milking parlours should consider the following factors before selecting a specific system. These factors also apply to new farmers wanting to start up a dairy. Factors to take in account include the following:

1. How many cows are to be milked daily in the milking parlour?
2. Which milking procedure will be used (minimal or full)?
3. If a full milking routine is to be used, how much contact time is required (strips per teat)?
4. Which milking routine is to be used (sequential, grouping or territorial)?
5. Would the milking parlour accommodate expansion in the future?
6. Are there major structural changes to be made to the existing parlour, or is a completely new building the preferred option?
7. Which feeding system is being used, e.g.
pasture-based, total mixed ration (TMR) or mixed system.
8. Are the facilities around the parlour, like holding yards, races, and pens, adequate for the changes, especially when an expansion of the herd is envisaged?
9. Is in-parlour concentrate feeding being considered?
10. What level of automation is required in (and outside) the parlour?
11. Is milk recording to be conducted, i.e. using approved milk meters?
12. What is the maximum milking time per day available?

Options for milking procedures and routines in parallel and herringbone parlours

It is essential that dairy producers develop accurate time budgets for the milking procedures and routines they select. Before the options for milking procedures and routines can be discussed, the following terms must be defined:

The actual time required for individual events during the milking process is shown in Table 53.1.

Table 53.1. Time (seconds) required for individual events of the milking procedure

<table>
<thead>
<tr>
<th>Event</th>
<th>Minimal*</th>
<th>Full</th>
<th>Full with 10 sec contact time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strip (seconds)</td>
<td>4 - 6</td>
<td>4 - 6</td>
<td>10</td>
</tr>
<tr>
<td>Pre-dip (seconds)</td>
<td>-</td>
<td>6 - 8</td>
<td>6 - 8</td>
</tr>
<tr>
<td>Wipe (seconds)</td>
<td>6 - 8</td>
<td>6 - 8</td>
<td>6 - 8</td>
</tr>
<tr>
<td>Attach (seconds)</td>
<td>8 - 10</td>
<td>8 - 10</td>
<td>8 - 10</td>
</tr>
<tr>
<td>Total (seconds)</td>
<td>12 - 18</td>
<td>24 - 32</td>
<td>30 - 36</td>
</tr>
</tbody>
</table>

*Strip or wipe and attach

Some of the advantages and disadvantages of minimal and full milking procedures are listed below.

1. Advantages and disadvantages of a minimal milking routine
   - Compromises teat skin sanitation.
   - Successful when cows enter the milking parlour clean and dry.
   - "Machine on-time" may be prolonged.
   - Steady unit throughput is increased.
   - Time required to milk the herd may be decreased (total milking time).
   - May require milkers to decide when extra cleaning of dirty teats is required.
   - Can cause lower milk quality and higher mastitis when compared to “full hygiene”.

2. Advantages and disadvantages of a full milking procedure
   - Maximises teat sanitation and milk let-down.
   - Uses 4 separate procedures or can combine into two or three procedures.
   - Use when maximum milk quality results are the goal.
   - Minimises "machine on-time".
   - Results in lower cow throughput or higher labour cost compared to “minimal” or “none”.
   - Requires milker training to maximise results.
Milking routines

Correct and proper managed routines in the parlour are of crucial importance. A proper routine is required to milk out cows completely. Anything outside the normal routine practice in the parlour adds to higher stress levels in cows, usually resulting in under-milking (not completely milked out) of cows. There are many negative factors that can disturb the daily routine, e.g.:

- Faulty settings of the milking machine, like the teat-end vacuum, or problems related to pulsation and vacuum levels,
- Abnormal noises,
- Change of milking times,
- Change in the handling of the cows prior to entering the parlour,
- Stray voltage (a cow reacts negatively to any stray voltage higher than 2 - 5 Volts), and
- Non-regular visitors in the parlour.

When a proper routine is followed and the stimulation of the cow’s milk let-down hormone is done efficiently, it is expected to milk-out cows completely.

In parallel and herringbone parlours, there are three milking routines, namely, grouping, sequential, and territorial.

1. **Grouping milking routine** - In a grouping routine, the milker performs all the individual tasks of the milking procedure on 4 to 5 cows. Once these tasks have been completed for a group of cows, the milker then moves on to the next group of available cows.

2. **Sequential milking routine** – Milkers using a sequential routine split up the individual tasks of the milking procedure between milkers and work as a team. Milkers work as a team following each other, performing their individual tasks.

3. **Territorial milking routine** - Milkers are assigned a number of milking units (clusters) on both sides of the parlour and only operate the units assigned to them. When a territorial routine is used, milkers are not dependent on other milkers to perform specific tasks.

The standard milking procedures for the minimal system include stripping milk, wiping teats, and attaching clusters, while the full system include pre-dipping, stripping milk, wiping teats, and attaching clusters. Full milking procedures affect the number of cows per stall per hour in parallel, herringbone, and rotary parlours. In large parallel and herringbone parlours cows per stall per hour are 5.2 - 6.5 cows per unit per hour when minimal milking procedures are used and 4.4 - 6.0 cows per unit per hour when full milking procedures are used. These figures will, of course, be affected by the level of training and other management procedures to be followed by milkers. In rotary parlours, cows per stall per hour would mainly be determined by the rotation speed of the milking platform and the routine to be followed.

In large parallel and herringbone milking parlours, milking procedures have a large effect on the number of milking units one milker is able to handle. When a full milking procedure is used, a milker should be able to operate 10 units on one side and 17 units on another side when using minimal milking procedures. These recommendations are based on allowing 4 - 6 seconds to strip a cow and attaching all the units on one side of the parlour in 4 minutes. In recent years, several milking management specialists have been recommending stripping 2 - 3 squirts per teat (in 8 - 10 seconds) when stripping cows to increase stimulation and improve milk let-down.

The reason for this is that unit-on-time is reduced by increasing udder stimulation. The sequencing of the individual events of the milking procedure is critical. Research has shown that an ideal prep-lag time is 1 minute and 18 seconds. Prep-lag times of 1-1.5 minutes seem to be accepted as optimal for all stages of lactation. Producers will have to decide which milking procedure they will use and the amount of stimulation that is required.

Selecting parlour type

Dairy farmers usually have a personal preference for a certain parlour type. Often this personal preference conflicts with the number of cows to be milked, length of the milking shift, anticipated milk quality, udder health results, and financial resources. The selection of a milking parlour is affected by the initial herd size, expansion plans, economic impact on the dairy, and the ability to train and manage employees. Dairy producers should visit as many types of milking parlours as possible and make a final decision after having an opportunity to review all types, which may
not necessarily be the fastest or latest milking machine and design.

**Total hours of use**

A milking parlour sized to be used for only 4 to 6 hours a day, will be more expensive to build and operate per cow than when the parlour operates 20 to 21 hours per day. For example, a 250 - cow dairy, milking twice a day could be milked in a double-4 herringbone parlour in a 6-hour shift, or milked in a double-10 herringbone in a 3-hour shift. Fewer hours of use may be desirable if farm personnel also have other duties, such as crop production, feeding, animal health, and raising replacements. However, a larger return on investment will be realised when the milking parlour can be used 20 to 21 hours a day to milk cows. Dairy farmers often have to make a choice between the number of cows that can be milked and which milking procedure they can use under these conditions. If not careful, milk quality and udder health may suffer with negative effects on milk yield.

**Number of milkers**

The number of milkers may be affected by the availability of personnel, milking procedure, or herd size. Most small herringbone and parallel milking parlours (double-4 to double-12) could be operated by 2 to 3 milkers for the bigger of the two milking parlours. One-person parlours are more efficient in the number of cows per labour hour. Two-or-more-operator parallel or herringbone parlours have the advantage of continuous operation, even during group change, when one operator is late for the milking shift, or when a short emergency requires one operator to leave the parlour. The disadvantage is that it is more difficult for the owner to assess operator performance or quality standards, and the number of cows per labour hour will be less. However, many producers are able to achieve the same labour efficiency in multiple operator parlours as single operator parlours with training and monitoring programmes.

**Initial herd size and expansion plans**

Dairy farmers should consider their current herd size along with plans to increase the herd size in the future. When a producer wants to grow the herd size in steps, parallel or herringbone parlours should be constructed to allow for expansion as the herd size increases.

Parallel and herringbone parlours have an advantage over rotary parlours which cannot be expanded in steps.

**One vs. two milking parlours (double pit parlours)**

Some research has indicated that two smaller milking parlours are more efficient than one larger milking parlour. Building two separate parlours also allows producers to construct the dairy in phases, while increasing the number of groups of lactating cows.

**Training and monitoring milkers**

Providing training and monitoring milkers are constant challenges for dairy producers. In parallel and herringbone parlours with multiple milkers, to improve parlour performance, it becomes very important to train teams of milkers to work together. In parallel and herringbone parlours, operators are mobile and able to perform multiple tasks (e.g. stripping, pre-dipping, wiping teats, and attaching clusters) as compared to rotary parlours where operators are fixed in one location and can only perform one or two tasks at this location. To maximise the performance of multiple operator parallel and herringbone parlours, milkers have to work together to perform the milking procedures over multiple cows using a grouping or sequential milking routine. After milker training has been completed, the dairy farmer will have to monitor the performance of individual milkers and parlour performance.

**Evaluating parlour performance**

Milking parlour performance has been evaluated by time and motion studies to measure steady-state throughput (cows per hour). Steady-state throughput does not include time for cleaning the milking system, maintenance of equipment, effects of group changing, and milking the hospital strings. These studies also allow for the opportunity to determine the effect of different management variables on milking parlour performance. Historically, this information has been used to size milking parlours towards meeting the requirements for dairy farmers.

**Sizing milking parlours**

As dairy herds increase in sizes, the sizing of milking parlours becomes more complicated. Many dairy farmers choose to use a so-called
hospital parlour (for cows under treatment for mastitis, etc.), thereby reducing the pressure of cow through-put in the main parlour. Some dairy farmers are also milking healthy cows in these hospital parlours to increase the number of cows to be milked. Some dairies are increasing the number of daily milkings from three to even five times a day, especially during the first 21-42 days of the lactation period, after which the number of daily milkings is reduced to two or three times per day. Such factors have a dramatic impact on how the milking parlour is sized.

Typically, milking parlours are sized so that the herd can be milked once in 10 hours when milking twice a day, 6.5 hours when milking three times a day, and 5 hours when milking four times a day. Using these criteria, the milking parlour will be sized to accommodate the cleaning and maintenance of the parlour. The facilities or cow groups are determined based on milking one group in 60 minutes when milking twice a day, 40 minutes when milking three times a day, and 30 minutes when milking four times a day. Group sizes of cows are adjusted to be divisible by the number of stalls on one side of the milking parlour. Having as many occupied stalls as possible per cycle maximises parlour efficiency.

The number of cows that will be milked per hour can be calculated using the following formulae:

\[
\text{Total number of stalls} \times \text{turns per stall per hour} = \text{cows milked per hour (CPH)}
\]

\[
\text{Number of milking cows} = \text{CPH} \times \text{milking shift length (hours)}
\]

Figure 53.1. An example of utilisation of labour with minimum routine, 4 operators, 72 unit rotary parlour

Sizing rotary parlours

Entry time (seconds/stall), number of empty stalls, number of cows which go around a second time, entry and exit stops, and the size of the parlour (number of stalls) influence the performance of rotary parlours. The entry time will determine the maximum number of cows that can be milked per hour. For example, if the entry time is 10 seconds, the maximum throughput will be 360 cows per hour (3600 seconds per hour / 10 seconds per stall = 360 cows per hour). This is referred to as theoretical throughput.

Theoretical throughput assumes that the parlour never stops, cows are milked out in 1 rotation and a new cow occupies every stall at entry. In reality, there are empty stalls (about 4 at any time, between getting on the table and getting off the table), cows that go around a second time, and times when the rotary table is stopped.

In Table 53.2, rotary parlour performance at different percentages of theoretical throughput is shown. As the number of empty stalls, cows making a second trip around, and number of stops increases, the percent of theoretical throughput is reduced.
The number of stalls or size of the rotary parlour affects the available unit-on-time. In Table 53.3, available unit-on-time for different sizes of rotary parlours at different rotation times is shown. A rotary parlour must be large enough to allow approximately 90 percent of the cows to be milked out in one trip around the parlour.

### Table 53.3. Available unit-on-time estimated for rotary parlours at different rotation times*

<table>
<thead>
<tr>
<th>Number of stalls</th>
<th>Entry time (sec/stall)</th>
<th>Revolution time</th>
<th>Available unit on time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Seconds per revolution</td>
<td>Minutes per revolution</td>
</tr>
<tr>
<td>40</td>
<td>8</td>
<td>320</td>
<td>5:20</td>
</tr>
<tr>
<td>40</td>
<td>10</td>
<td>400</td>
<td>6:40</td>
</tr>
<tr>
<td>40</td>
<td>12</td>
<td>480</td>
<td>8:00</td>
</tr>
<tr>
<td>40</td>
<td>15</td>
<td>600</td>
<td>10:00</td>
</tr>
<tr>
<td>60</td>
<td>8</td>
<td>480</td>
<td>8:00</td>
</tr>
<tr>
<td>60</td>
<td>10</td>
<td>600</td>
<td>10:00</td>
</tr>
<tr>
<td>60</td>
<td>12</td>
<td>720</td>
<td>12:00</td>
</tr>
<tr>
<td>60</td>
<td>15</td>
<td>900</td>
<td>15:00</td>
</tr>
<tr>
<td>72</td>
<td>8</td>
<td>576</td>
<td>9:22</td>
</tr>
<tr>
<td>72</td>
<td>10</td>
<td>720</td>
<td>12:00</td>
</tr>
<tr>
<td>72</td>
<td>12</td>
<td>864</td>
<td>14:24</td>
</tr>
<tr>
<td>72</td>
<td>15</td>
<td>1080</td>
<td>18:00</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>640</td>
<td>10:40</td>
</tr>
<tr>
<td>80</td>
<td>10</td>
<td>800</td>
<td>13:20</td>
</tr>
<tr>
<td>80</td>
<td>12</td>
<td>960</td>
<td>16:00</td>
</tr>
<tr>
<td>80</td>
<td>15</td>
<td>1500</td>
<td>20:00</td>
</tr>
</tbody>
</table>

*Assumes 5 stalls for entry and exit, 3 stalls for pre-milking hygiene, and 2 stalls to detach

In reviewing the data available today, rotary parlours should be sized at an 11-12 seconds per stall rotation and 81% of theoretical throughput. The parlour should be large enough to allow nine minutes of available unit-on-time. When sizing rotary parlours on a steady state throughput basis, approximately 5 and 5.8 cows are milked per stall per hour for milking parlours with less than 54 and 60 stalls, respectively (Table 53.4). Milking parlours with 60 stalls or larger are able to increase the number of rotations per hour and still maintain adequate time to milk cows completely out, without some cows going around a second time. It is critical that rotary parlours be sized to accommodate some expansion because they are very difficult to expand.
Research showed that when automatic cluster remover settings were increased, average milking duration was reduced by 10.2 to 15.6 seconds per cow. Higher automatic cluster remover settings did not have a negative impact on the milk yield of cows. The average milk flow per minute also increased. The conclusion was that increasing automatic cluster remover settings represents an opportunity to increase parlour performance.

Herd size and feeding practice determine the level of automation

In essence, there are four parlour lay-out choices for medium to large scale dairy farming:
- Rotary parlours (internal or external configuration)
- Big Bore or swing-over herringbone parlours
- Double sided herringbone parlours
- Parallel or rapid exit parlours

The choice is very much determined by herd size and the cow throughput that is required, and varies from farm to farm. Management style, personal preference and finance available are some of the most important factors that will decide on the choice made. The number of milking units will be determined by the milking time available, as well as by the herd size and feed practice.

Level of automation required

The level of automation in the milking parlour is largely affected by the management level required for the dairy. Usually this includes equipment like electronic milk meters, automatic cluster removers, and milk flow control devices. Computer programmes that help with daily decisions like calving data, lactation data, milking records, cow performance figures and historical data to name only a few, make management easier for the dairy farmer. One should remember that a management programme is as useful as the data that is put into it. Computerised management systems are becoming a very important tool for many dairy farmers on which to base daily management decisions.

The basic norms for modern milking machines

A large volume of information is available on this topic, and international standards are available to assist the manufacturers of milking equipment to ensure that machines will be fully operational once installed. The international ISO standards are widely used as the correct norm for this purpose, and many aspects are dealt with in these norms. Important aspects covered in the ISO standards that are researched continuously, and that may affect the milk harvesting process negatively, include the following:
- Milk and vacuum line design for different size machines,
- Cleaning capacity design,
- Pulsator characteristic design,
- Vacuum drops between different points in the milking machine that are allowed, and
- The important aspect of teat end vacuum level specification, which is surely the most important measurement to do to secure that damage to the cow’s teats is eliminated. It should be between 32 and 40kPa according to ISO norms, and can only be tested with specialised equipment.

Table 53.4. Results from a survey conducted in the USA showing the performance of different sized rotary milking parlours using a full milk procedure

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Number of milking parlour stalls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 - 40</td>
</tr>
<tr>
<td>Number of milking parlours</td>
<td>8</td>
</tr>
<tr>
<td>Average number of stalls</td>
<td>36</td>
</tr>
<tr>
<td>Average number of cows/hour</td>
<td>181</td>
</tr>
<tr>
<td>Average number of milkers</td>
<td>2.6</td>
</tr>
<tr>
<td>Average number cows labour/hour</td>
<td>82</td>
</tr>
<tr>
<td>Average milk yield (kg/day)</td>
<td>32</td>
</tr>
<tr>
<td>Average rotation/stall/hour</td>
<td>5.42</td>
</tr>
<tr>
<td>Average cows/stall/hour</td>
<td>5.01</td>
</tr>
</tbody>
</table>
Robotic milking – a future option

Hundreds of dairy farmers world-wide are milking their cows by robotic or voluntary milking systems. In such systems, cows decide when they want to be milked (most of the times cows visit the milking parlour 4 to 6 times per day), and during milking, various parameters like teat end condition compared to previous milkings, milk quality evaluation, cleaning and drying of each teat, the milking of each quarter individually, the cleaning of the teat cups after milking and post dipping, are recorded automatically. This information is then included in the herd management programme. In some cases specific information can be sent to a mobile phone. The limitation of the voluntary milking system is the number of cows that can be milked per station. Currently, 60 - 70 cows can be milked with one machine. In the near future, robotic milking machines will be improved, which should make them more affordable. Adaptations to current parlour configurations should also follow towards more automation.

In closing

The choice of milking equipment and the type of parlour depends on the level of automation and information that is required for the daily management of the dairy herd. Together with these choices, the availability of services and spares on an ongoing basis will aid the decision making process. The welfare of cows should be considered when considering different milking parlour options. Milk is produced from fewer, but higher yielding cows. Structural changes have caused a decrease in number of dairy farms, while they have increased in size and use of technology. This high technology has become an ordinary tool for the dairy farmer. It should be kept in mind that milking is not only a procedure where the milk is drained from the teats, it is an event where many physiological mechanisms are activated in the body of the lactating cow, events which influence mechanisms regulating production capacity, milk composition, feed intake and animal behaviour.