# **ILRI Training Manual 1**

# **Rural Dairy Technology**

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Charles B. O'Connor

# Foreword

This training manual is based largely on ILCA Manual No. 4 written by the late Frank O'Mahony.

As a result of experiences and suggestions obtained particularly from participants in our Rural Dairy Processing training courses it was considered necessary to provide a more comprehensive manual with more up to date technical information. Emphasis has been given to clean milk production as milk is our raw material for processing and preservation. In recognition of the need to comply with hygienic and compositional requirements of milk and milk products the chapter on analytical methods has been expanded. To recognise the importance of water in milk processing, water-quality standards are discussed and methods for the determination of its chemical quality are detailed.

Milk production and processing is an important activity of smallholders throughout the world and with the help of this manual it is hoped that dairy technologists and extension workers will further assist and promote the development of milk processing particularly in countries with a developing dairy industry.

> Michael E. Smalley Director of Training and Information

# 1. Introduction

Milk and milk products have been used by man since prehistoric times. There is evidence that butter was made as far back as 2000 BC. It is thought that cheesemaking was discovered accidentally and initially developed in Iraq circa 7000–6000 BC and spread with the migration of populations due to famines, conflicts and invasions. Examples of these migrations are the development of Swiss cheeses by the Helveti tribe in Switzerland and the introduction of cheesemaking into England by the Romans. Cheese varieties peculiar to each region developed because of the different agricultural conditions prevailing in each country. There are, at present, almost 2000 recognised varieties of cheese.

Fermented milks have been prepared for more than 2000 years. Allowing milk to ferment naturally gives an acidic product that does not putrefy. Fermented milks are wholesome and readily digestible; examples of such products are yoghurt, *kefir, koumiss* and acidophilus milk.

The development of the milk separator in the 19<sup>th</sup> century made centralised milk processing possible. Initially, cream was separated and retained for buttermaking and the fresh skim milk was returned to the milk producers. As the nutritional importance of the non-fat component (skim milk) became recognised, processes were developed to conserve milk solids-not-fat (SNF). Casein and casein products as well as lactose and dried milk were prepared. Today, up to 60% of the milk produced in the world is converted into dehydrated milk products and foods containing a large proportion of milk solids. In countries with commercial dairying these processes are carried out in large-capacity processing plants.

In Africa, milk is produced in most agricultural production systems. It is either sold fresh, consumed as fermented milk or manufactured into products such as butter, ghee and cheese. Sour milk is the most common product, and milk is usually soured before further processing. While there are several milkprocessing plants in Africa, much of the milk produced by rural smallholders is processed on-farm using traditional technologies. It is important, therefore, to consider these processes and look to possible technological interventions at this level when considering dairy development in the rural sector.

Farmers in many African countries produce sour milk, butter and cottage cheese for home consumption and sale. The Maasai in Kenya make ghee from sour milk. Fermented milks are made throughout sub-Saharan Africa, and concentrated fermented milks are made in some parts of the continent. While the processes used have not been subject to extensive scientific investigation, they appear to be effective methods of converting milk into stable marketable products and have long been used for processing surplus milk.

Milk is processed primarily to convert it into a more stable product, e.g. fermented milk can be stored for about 20 days compared with less than one day for fresh milk. Milk products are more stable than fresh milk because they are more acidic and/or contain less moisture. Preservatives, e.g. salt may also be added to milk products. Thus, by increasing the acidity and reducing the moisture content, the storage stability of milk can be increased.

This manual deals with milk processing in a rural and small-scale environment. It concentrates on traditional products or on products that are easily made, need little specialised equipment and can be easily adapted to the rural processing plant. Some background information in the areas of milk chemistry, dairy microbiology and milk and milk-product analysis is also given.

# 2. Milk as a food

Milk is secreted by the mammary glands of mammals to feed their young. Cow milk — a white fluid of low viscosity and slightly sweet taste — is most commonly used as human food. There are, however, wide variations in the chemical and physical properties of the milk of various mammalian species as shown in Table 1. The table gives the average gross composition values of milk from some common species.

Species	Total solids	Fat	Protein	Lactose	Ash
Human	12.4	3.8	1.0	7.0	0.2
Cow	12.7	3.7	3.4	4.8	0.7
Goat	12.3	4.5	2.9	4.1	0.8
Sheep	19.3	7.4	5.5	4.8	1.0
Horse	11.2	1.9	2.5	6.2	0.5
Donkey	11.7	1.4	2.0	7.4	0.5
Domestic rabbit	32.8	18.3	13.9	2.1	1.8
Camel	12.9	4.2	3.7	4.1	0.9

 Table 1.
 Composition (%) of milk of some species of mammal.

Milk is the sole source of nutrients for most young mammals for lengths of time which vary with the species. Overall, milk serves the following broad functions for both young and old: (a) growth, (b) reproduction, (c) supply of energy, (d) maintenance and repairs and (e) appetite satisfaction. The requirements of these categories vary with the individual, and in some instances not all the stated functions of the food need to be served, e.g. adults do not require food for growth whereas infants do. To fulfil its functions as a food milk contains various nutritionally important components, namely proteins, carbohydrates, lipids, minerals, vitamins and water.

The gross energy supplied by milk can be calculated from its lactose, protein and fat contents. The metabolically available energy is approximately 4.0, 4.1 and 8.9 kcal/g (16.8, 17.0 and 37.0 kJ/g) for lactose, protein and fat, respectively. On the basis of the data in Table 1 human and cow milk contain 670–720 kcal/kg (2.8–3.0 MJ/kg).

The chief function of lactose in milk is to supply energy for muscular activity and maintenance of body temperature. Like other disaccharides, lactose must be hydrolysed to its monosaccharide components, glucose and galactose, before it is absorbed across the intestinal membrane into the blood stream. Some people cannot tolerate lactose because they lack the enzyme (lactase) which is required to hydrolyse it. Lack of lactase may result in abdominal cramps, bloating and diarrhoea on drinking milk. When lactose is removed from milk, or converted into lactic acid during cheese manufacture, milk products can be consumed by lactose-intolerant people. Lactose has certain therapeutic properties and is known to enhance the intestinal absorption of calcium and phosphorus. Its presence in the intestine favours an acid-type fermentation which may prevent intestinal disorders. Fermented milks may be preferable to fresh milk because they prevent the propagation of infectious diseases.

Proteins are essential for the growth and maintenance of all cells in the body. The value of milk proteins depends primarily on their content of some nine essential amino acids which cannot be synthesised by the body. Cow and human milk contain all the essential amino acids required for human infants. Fortunately, both cow and human milk are easily digested and the amino acids are readily absorbed.

Cow milk (3.4% protein) forms a rather firm curd in the stomach and digestion is slower than with human milk, which contains about 1% protein. Diluting cow milk with water or high heat treatment softens the curd.

Lipids supply the body with a concentrated source of energy and are also important contributors to both desirable and undesirable flavours in milk and milk products. Certain fatty acids are not synthesised by the animal. They include the polyunsaturated acids, linoleic ( $C_{18:2}$ ) acid and probably linolenic ( $C_{18:3}$ ) acid. It is considered that 2–4% of the total energy of the diet should be supplied by polyunsaturated acids. The linoleic acid contentin human milk fat accounts for approximately 5% of the energy in milk. This is much higher than for cow milk fat which accounts for only about 1% of the total energy.

Human and cow milk are excellent sources of vitamins. Vitamins A, D, E and K occur in the fat phase and the others in the aqueous phase of milk. Milk is a major source of some of the vitamins needed by infants and adults. It is relatively rich in vitamins A and E, thiamin, riboflavin, folic acid and vitamin  $B_{12}$ . However, large variations occur between human and cow milk. Human milk contains only about 35% as much thiamin, 25% as much riboflavin and 5% as much  $B_{12}$  as cow milk. On the other hand, human milkcontains about 10 times as much vitamin E and 2.5 times as much ascorbic acid as cow milk. In many countries milk is fortified with vitamins A and D. Vitamin A is central to the visual process as a constituent of the visual pigment rhodopsin. Vitamin D is essential for the calcification processes in the body, including bone and teeth formation.

Milk is also an excellent source of many minerals and supplies virtually all of the minerals required by humans. Cow milk furnishes a major portion of the total calcium consumed in many countries. The high levels of calcium and phosphorus in milk are important in bone and tooth formation in young children; both these elements play a significant role in preventing osteoporosis in elderly people. Milk also contains high levels of magnesium, zinc and iodine. However, milk is a poor source of iron and neither human nor cow milk supply enough for human infants. Fortunately, infants have a store of iron in the liver which is sufficient to meet the needs of the body during the first six months.

The nutritive value of milk may be considerably altered by processes such as separation, concentration of the components, addition of non-milk constituents and heat treatment. For example, during buttermaking the fat and fat-soluble vitamins are retained in the butter while the protein, lactose, minerals and B vitamins remain in the buttermilk. Part of the fat in butter can be replaced by vegetable oil to give better spreadability. Diluting cow milk with water or severe heat treatment greatly softens the casein curd and allows for easy digestion. When mother's milk is not available milk formulations for babies are prepared by mixing cow milk, cream, whey proteins, lactose and water. The ratio of casein to whey, protein, the lactose content and salts in milk formulations are similar to those of human milk.

Mild heat treatment such as pasteurisation or ultra high temperature (UHT) processing cause very little change in nutritive value. Severe heat treatment results in some loss of available lysine, but this has little effect on the nutritional quality because milk proteins are rich in lysine. The interaction between lysine and lactose during heating results information of a brown pigment (Maillard browning) that causes off-flavours to develop during storage of milk products.

Figure 1 shows the major milk constituents and a range of products that can be manufactured from these constituents.



Figure 1. Flow chart illustrating the incorporation of the major milk-solid fractions in milk products.

# 3. The composition of milk

Milk composition is affected by a number of factors including genetic and environmental factors.

# 3.1 Genetic factors

### 3.1.1 Breed and individuality of the cow

Both milk yield and composition vary considerably among breeds of dairy cattle. Jersey and Guernsey breeds give milk with about 5% fat while the milk of Shorthorns and Friesians contains about 3.5% fat. Zebu cows can give milk containing up to 7% fat.

Table 2 gives the average composition of milk from different breeds of cow.

Breed	Fat	Protein	Lactose	Ash
Zebu	5.6	3.1	4.6	0.71
Ayrshire	3.8	3.4	4.8	0.70
Friesian	3.4	3.2	4.6	0.74
Guernsey	4.9	3.8	4.8	0.75
Jersey	5.1	3.8	4.9	0.75
Shorthorn	3.6	3.4	4.8	0.70

Table 2. Average composition (%) of cow milk.

Milk of individual cows within a breed varies over a wide range both in yield and in the content of the various constituents.

The potential fat content of milk from an individual cow is determined genetically, as are protein and lactose levels. Thus selection for breeding on the basis of individual performance is effective in improving milk compositional quality. Herd recording of total milk yields and fat and solids-not-fat (SNF) percentages will indicate the most productive cows, and replacement stock should be bred from these.

# 3.2 Environmental factors

# 3.2.1 Interval between milkings

The fat content of milk varies considerably between the morning and evening milking because there is usually a much shorter interval between morning and evening milking than between evening and morning milking. If cows were milked at 12-hour intervals the variation in fat content between milkings would be negligible, but this is not practicable on most farms. Normally, SNF content does not vary with the length of time between milkings.

# 3.2.2 Stage of lactation

The fat, lactose and protein contents of milk vary according to stage of lactation. Solids-not-fat content is usually highest during the first two to three weeks, after which it decreases slightly. Fat content is high immediately after calving but soon begins to fall, and continues to do so for 10 to 12 weeks, after which it tends to rise again until the end of the lactation. The high protein content of early lactation milk is due mainly to the high globulin content. The variation in milk constituents throughout lactation is shown in Figure 2.



### 3.2.3 Age and health

As cows grow older the fat content of their milk decreases by about 0.02 percentage units per lactation while the fall in SNF content is about 0.04 percentage units. Both fat and SNF contents can be reduced by disease, particularly mastitis.

# 3.2.4 Feeding regime

Underfeeding reduces both the fat and the SNF content of milk, although SNF content is the more sensitive to feeding level. Fat content and fat composition are influenced more by roughage (fibre) intake.

The SNF content may fall if the cow is fed a low-energy diet, but is not greatly influenced by protein deficiency, unless the deficiency is acute.

### 3.2.5 Completeness of milking

The first milk drawn from the udder contains about 1.4% fat while the last milk (or strippings) contains about 8.7% fat. Thus, it is essential to milk the cow completely and thoroughly mix all the milk removed before taking a sample for analysis. The fat left in the udder at the end of a milking is usually picked up during subsequent milkings, so there is no net loss of fat.

# 4. Milk chemistry

# 4.1 Physical status of milk

About 87% of milk is water, in which the other constituents are distributed in various forms. Several kinds of distribution are distinguished according to the type and size of particle present in the liquid.

Kind of solution	Particle diameter (nm)
Ionic solution	0.01-1
Molecular solution	0.1–1
Colloid (fine dispersion)	1–100
Coarse dispersion	
(suspension or emulsion)	50-100

In milk, examples of emulsions, colloids, molecular and ionic solutions are found.

### 4.1.1 Ionic solutions

An ionic solution is obtained when the forces that hold the ions together in a solid salt are overcome. The dissolved salt breaks up into ions which float freely in the solvent. Thus when common salt — sodium chloride — is dissolved in water it becomes an ionic solution of free sodium and chloride ions. Ionic solutions are composed largely of inorganic compounds.

### 4.1.2 Molecular solutions

In a molecular solution the molecules are only partly, if at all, dissociated into ions. The degree of dissociation represents an equilibrium which is influenced by other substances in the solution and by the pH (or hydrogen ion concentration) of the solution. Molecular solutions are usually composed of organic compounds.

# 4.1.3 Colloids

In a colloid, one substance is dispersed in another in a finer state than an emulsion but the particle size is larger than that in a true solution. Colloidal systems are classified according to the physical state of the two phases. In a colloid, solid particles consisting of groups of molecules float freely. The particles in a colloid are much smaller than those in a suspension and a colloid is much more stable.

# 4.1.4 Emulsions

An emulsion consists of one immiscible liquid dispersed in another in the form of droplets — the disperse phase. The other phase is referred to as the continuous phase. The systems have minimal stability and require a surface-active or emulsifying agent, e.g. lecithin in milk, for stability. In foods, emulsions usually contain oil and water. If water is the continuous phase and oil the disperse phase, it is an oil-in-water (o/w) emulsion, e.g. milk or cream. In the reverse case the emulsion is a water-in-oil (w/o) type, e.g. butter.

### 4.1.5 Dispersions

A dispersion is obtained when particles of a substance are dispersed in a liquid. A suspension consists of solid particles dispersed in a liquid, and the force of gravity can cause them to sink to the bottom or float to the top. For example, fine sand, dispersed in water, soon settles out.

# 4.2 pH and acidity

An acid is a substance which dissociates to produce hydrogen ions in solution. A base (alkaline) is a substance which produces hydroxyl ions in solution. It can equally be stated that an acid is a substance which donates a proton and a base is a substance which accepts a proton.

The symbol pH is used to denote acidity; it is inversely related to hydrogen ion concentration. On a scale of 0–14:

Neutrality = pH 7 Acidity is < pH 7 Alkalinity is > pH 7

Fresh milk has a pH of 6.7 and is therefore slightly acidic.

When an acid is mixed with a base, neutralisation takes place; similarly a base will be neutralised by an acid.

### 4.2.1 Buffer solutions

Buffers are defined as materials that resist change in pH on addition of acid or alkali. Characteristically they consist of a weak acid or a weak base and its salt. Milk contains a large number of these substances and consequently behaves as a buffer solution. Fresh cow milk has a pH of between 6.5 and 6.7. Values higher than 6.7 indicate mastitic milk and values below pH 6.5 indicate the presence of colostrum or bacterial deterioration. Because milk is a buffer solution, considerable acid development may occur before the pH changes. A pH lower than 6.5 therefore indicates that considerable acid development has taken place. This is normally due to bacterial activity.

Litmus test papers, which indicate pH, are used to test milk acidity; pH measurements are often used as acceptance tests for milk.

Milk acidity is an important indicator of milk quality. Acidity measurements are also used to monitor processes such as making cheese and yoghurt. The titratable acidity of milk is expressed in terms of percentage lactic acid — the principal acid produced by fermentation after milk is drawn from the udder. Fresh milk contains only traces of lactic acid. However, due to the buffering capacity of the proteins and milk salts fresh milk, in which no lactic acid has been produced, normally exhibits an initial acidity of 0.14 to 0.16% when titrated using sodium hydroxide to a phenolphthalein end-point.

# 4.3 Milk constituents

The quantities of the main milk constituents can vary considerably depending on the individual animal, its breed, stage of lactation, age and health status. Herd management practices and environmental conditions also influence milk composition. The average composition of cow milk is shown in Table 3.

Water is the main constituent of milk and milk processing is usually designed to remove water from milk or reduce the moisture content of the product.

#### 4.3.1 Fat

If milk is left to stand, a layer of cream forms on the surface. The cream differs considerably in appearance from the lower layer of skim milk.

Main constituent	Range (%)	Mean (%)
Water	85.5-89.5	87.0
Total solids	10.5–14.5	13.0
Fat	2.5-6.0	4.0
Proteins	2.9–5.0	3.4
Lactose	3.6–5.5	4.8
Minerals	0.6–0.9	0.8

**Table 3.**Composition of cow milk.

Cream consists of a large number of spherical microscopic globules of varying sizes floating in the milk. Each globule is surrounded by a thin skin — the fat globule membrane — which acts as the emulsifying agent for the fat suspended in milk (Figure 3). The membrane protects the fat from enzymes and prevents the globules coalescing into butter grains. The fat is present as an oil-in-water emulsion that can be broken by mechanical action such as shaking.

Figure 3. Fat globules in milk.



Fats are partly solid at room temperature. The term oil is reserved for fats that are completely liquid at room temperature. Fats and oils are soluble in non-polar solvents, e.g. ether. The lipid content of milk is usually defined as the fraction which is extracted by organic solvents. Table 4 gives the main lipid classes of milk fat.

Table 4.	Composition	of lipids	in	whole	bovine	milk.
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Lipid	Weight (%)
Carotenoids + vitamin A	trace
Cholesterol esters	0.02
Triglycerides	98.3
Diglycerides	0.3
Monoglycerides	0.03
Free fatty acids	0.1
Cholesterol	0.20-0.40
Phospholipids	0.20-1.0

About 98% of milk fat is a mixture of triacyl glycerides. The partial glycerides (diglycerides and monoglycerides) and free fatty acids are probably partly left over from the biosynthesis process. Also present are fat soluble vitamins A, D, E and K and pigments, e.g. carotene which gives butter its natural yellow colour. Examples of each type of fatty acid are shown in Figure 4. The main variables are as follows:

- 1. Chain length. Fatty acids vary in chain length from 4 carbon atoms, as in butyric acid, to 20 carbon atoms, as in arachidic acid. Nearly all the fatty acids in milk contain an even number of carbon atoms. Milk fat contains significant levels of short and medium chain fatty acids. Butyric acid (C4) is specific for milk fat of ruminant species.
- 2. Number of double bonds. A fatty-acid molecule comprises a hydrocarbon chain and a carboxyl group (-COOH). In saturated fatty acids the carbon atoms are linked in a chain by single bonds (e.g. stearic acid,  $C_{18:0}$ , in Figure 4). Unsaturated fatty acids have one double bond, e.g. oleic acid,  $C_{18:1}$ , while polyunsaturated fatty acids have more than one double bond, e.g. linoleic acid,  $C_{18:2}$  (two double bonds), and linolenic acid,  $C_{18:3}$  (three double bonds). It is the double bonds in the carbon chain that make the fatty acid unsaturated. Two hydrogens can be added per double bond at high temperature with a suitable catalyst. This process is called hydrogenation and has the effect of converting a soft fat to a hard fat at room temperature.

Figure 4. Structural formulae of four 18-carbon fatty acids varying in degree of saturation.

Stearic acid C18:0



Linoleic acid C18:2



Linoleic acid C18:3



- 3. Position of double bond. The double bond can occur in many positions (called isomers). Oleic acid has the double bond at the ninth position which may be indicated as follows :  $C_{18:1}$  9. Linoleic acid has two double bonds at the ninth and twelfth positions which may be indicated as follows:  $C_{18:2}$  9, 12.
- 4. The proportion of saturated fatty acids present in milk fat is about 63%.
- 5. Oleic acid is the most abundant of the unsaturated fatty acids.

Fatty acid	Molecular formula	Average amount in milk fat (%)	Chain length (No. of carbons)	Melting point (°C)
Butyric	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>2</sub> COOH	3.7	4	-8
Caproic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> COOH	2.0	6	-2
Caprylic	CH <sub>2</sub> (CH <sub>2</sub> ) <sub>6</sub> COOH	1.6	8	16
Capric	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>8</sub> COOH	2.6	10	31.5
Lauric	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> COOH	3.3	12	44
Myristic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>12</sub> COOH	8.7	14	58
Palmitic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>14</sub> COOH	27.0	16	64
Stearic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>16</sub> COOH	10.0	18	70
Oleic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH=CH(CH <sub>2</sub> ) <sub>7</sub> COOH	35.0	18	13
Linoleic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> (CH=CH.CH <sub>2</sub> ) <sub>2</sub> (CH <sub>2</sub> ) <sub>6</sub> COOH	4.5	18	-6
Linolenic	CH3.CH2(CH=CH.CH2)3(CH2)6COOH	0.6	18	-13
Arichidic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>18</sub> COOH	1.0	20	77

#### **Table 5.***Principal fatty acids found in milk triglycerides.*

The most important fatty acids found in milk triglycerides are shown in Table 5. Fatty acids are esterified with glycerol as follows:

H <sub>2</sub> _C–OH	HOOC-R <sub>1</sub>	$H_2-C-OOCR_1$		
Н–С–ОН +	$HOOC-R_2 \longrightarrow$	H-C-OOCR <sub>2</sub>	+	3H <sub>2</sub> O
Н2-С-ОН	HOOC-R <sub>3</sub>	H <sub>2</sub> -C-OOCR <sub>3</sub>		
Glycerol +	fatty acids ——>	triglyceride (fat)	+	water

The melting point and hardness of the fatty acid is affected by the length of the carbon chain and the degree of unsaturation. As chain length increases, melting point increases. As the degree of unsaturation increases, the melting point decreases.

Fats composed of short-chain or unsaturated fatty acids have low melting points and are liquid at room temperature, i.e. oils. Fats high in long-chain saturated fatty acids have high melting points and are solid at room temperature. Butterfat is a mixture of fatty acids with different melting points and therefore does not have a distinct melting point. Since butterfat melts gradually over a temperature range of  $0-40^{\circ}$ C, some of the fat is liquid and some solid at temperatures between 16 and 25°C. The ratio of solid to liquid fat at the time of churning influences the rate of churning and the yield and quality of butter.

Fats readily absorb flavours, e.g. butter made in a smoked gourd has a smoky flavour. Lipids in foods are subject to two forms of deterioration that affect the flavour of food products:

#### Hydrolytic rancidity

Lipolysis, which is the breaking down of milk fat into component fatty acids, increases the concentration of free fatty acids. Lipolysis is induced by the action of naturally occurring lipase in milk which hydrolyses the

triacylglycerides. The C<sub>4</sub> to  $C_{12}$  fatty acids in milk are the major contributors to detectablerancidity since they are relatively water soluble and volatile at room temperature. The extent of lipolysis is usually expressed as the acidity or acid degree value of the fat (expressed as millimoles or grams of free fatty acid–oleic acid per 100 grams of fat).

Susceptibility of milk to lipolysis varies widely among cows. Lipolysis increases with stage of lactation and varies inversely with milk yield. Feeding rations of low quality may also increase lipolysis in the milk. The susceptibility of milk tolipolysis is increased by homogenisation, pumping, foaming and temperature manipulation. For example when milk is cooled to 5°C, rewarmed by adding hot milk and cooled again to 5°C, the extent of lipolysis is increased; pasteurisation (72.8°C x 15 seconds) inactivates the enzyme responsible.

The flavour caused by free fatty acids is not always undesirable. Free fatty acids contribute to the desirable flavour of several cheese varieties, e.g. Cheddar, Camembert and Roquefort.

#### **Oxidative rancidity**

The oxidative deterioration of lipids is caused by oxidation (involving oxygen) of unsaturated fatty acids — mainly oleic, linoleic and linolenic acids — resulting in the production of volatile aldehydes, ketones and alcohols. A variety of factors influence the rate of oxidation. Undoubtedly the most important factor is the composition of the fat, i.e. the nature and proportion of unsaturated fatty acids present. For example linoleate oxidises 10 to 15 times as fast as oleate. The main factors accelerating the rate of lipid oxidation are high temperature, light and trace elements (copper, iron etc). Oxidation is inhibited by exclusion of oxygen, refrigeration and packaging in opaque or coloured containers.

### 4.3.2 Proteins

Proteins are an extremely important class of naturally occurring compounds that are essential to all life processes. They perform a variety of functions in living organisms ranging from providing structure to reproduction. Milk proteins represent one of the greatest contributions of milk to human nutrition.

Proteins are polymers of amino acids. Only 20 different amino acids occur regularly in proteins. They have the following general structure:

$$R - C - COOH H$$

R represents the organic radical. Each amino acid has a different radical and this affects the properties of the acid. The content and sequence of amino acids in a protein therefore affect its properties. Some proteins contain substances other than amino acids and are called conjugated proteins. These include :

- Phosphoproteins in which phosphate is linked chemically to the protein, e.g. casein in milk and phosphoproteins in egg yolk.
- Lipoproteins which are combinations of lipid and protein and are excellent emulsifying agents. They
  are found in milk and egg yolk.
- Chromoproteins which have a coloured prosthetic group and include haemoglobin and myoglobin.

#### Protein composition of milk

Cow milk contains about 32 g/litre protein. Of this, about 26 g/litre consists of caseins which are precipitated upon acidification to pH 4.6 at temperatures above 20°C. The proteins(6 g/litre) remaining in solution at pH 4.6 are called whey proteins and consist of a diverse group including  $\alpha$ -lactalbumin,  $\beta$ -lactoglobulin, blood serum albumin and immunoglobulins (Figure 5).

#### Caseins

Casein was first separated from milk in 1830 by adding acid to milk, thus establishing its existence as a distinct protein. It was subsequently shown that casein is made up of a number of fractions and is therefore

heterogeneous (Figure 5). About four kinds of polypeptide chains designated  $\alpha_s$  (which can be broken down during cheese ripening to  $\alpha_{s1}$ ,  $\alpha_{s2}$  and  $\alpha_{s3}$ ),  $\beta$ - and k-caseins, together with some derivatives, e.g. Y-casein, formed by proteolysis of these chains, are included in the casein category. In general caseins are high in phosphorus, low in sulphur and are not significantly affected by moderate heat.





All the major caseins associate with themselves and with each other. In the presence of calcium ions  $(Ca^{++})$  these associations lead to the formation of casein micelles. About 95% of the casein in milk exists as particles of colloidal dimensions known as micelles. The micelles are generally spherical in shape with diameters ranging from 40 to 300 nm (average about 100 nm) and molecular weight of about  $10^8$ .

Case in is easily separated from milk by acid precipitation at about pH 4.6. Industrially, hydrochloric acid (HCl) is the principal acid used; sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) is used occasionally, but the resulting whey cannot be used for animal feed as it may cause intestinal disorders. Lactic acid produced in milk by lactic acid bacteria is widely used in some countries, e.g. New Zealand in the production of industrial case in.

When milk is treated with rennin the k-casein fraction is hydrolysed to give para-k-casein and macropeptides. In the presence of  $Ca^{++}$  casein coagulates as follows:



#### Whey proteins

When milk is brought to pH 4.6, the caseins precipitate. The supernatant contains four principal proteins in the whey fraction,  $\beta$ -lactoglobulin,  $\alpha$ -lactalbumin, blood serum albumin, immunoglobulins and a number of minor proteins, e.g. lactoferrin and enzymes. Most of the whey proteins are denatured by heat, i.e. they become less soluble if milk is heated.  $\beta$ -lactoglobulin is the principal whey protein of the cow, goat and sheep, although there are slight interspecies differences.  $\beta$ -lactoglobulin accounts for about 50% of the total whey proteins or about 11% of the total protein in milk. Related but substantially different proteins occur in porcine milk. No  $\beta$ -lactoglobulin has been identified in human, camel or horse milk in which  $\alpha$ -lactalbumin is the principal whey protein.

Denaturation of whey proteins and  $\beta$ -lactoglobulin, in particular, is of major technological significance.  $\beta$ -lactoglobulin interacts with k-casein during heating and this reduces the heat stability of milk, slows down rennet clotting during cheese manufacture and gives a soft curd which tends to retain water.

 $\alpha$ -lactalbumin represents about 20% of the protein of bovine whey (3.5% of the total milk protein) and is a relatively minor protein in terms of quantity. It functions as part of the enzyme system involved in lactose synthesis.

The immunoglobulins are antibodies which are present in high concentrations in colostrum. Infants and mammals are born without circulating antibodies and the main way in which they acquire these is by ingestion of colostrum.

#### Minor protein constituents

About 50 enzymes have been detected in bovine milk. The concentration of milk enzymes varies greatly among species. Some milk enzymes act on substrates present as normal constituents of milk and may play either beneficial or deleterious roles during milk processing.

**Catalase.** This enzyme catalyses the decomposition of hydrogen peroxide  $(H_2O_2)$  to  $H_2O$  and  $O_2$ . Its activity is higher in mastitic milk and colostrum than in normal milk and increases with increase in bacterial numbers.

**Lactoperoxidase.** This enzyme catalyses oxidation of a range of substrates by  $H_2O_2$ . The enzyme catalyses oxidation of thiocyanate to products that inhibit certain bacteria. It is relatively heat stable; it is not inactivated by pasteurisation (72°C x 15 seconds) but is destroyed when milk is heated above 80°C. The absence of lactoperoxidase in milk indicates that the milk has been heated to at least 80°C. The test for the presence of lactoperoxidase is based on the oxidation of the substrate para-phenylenediamine in the presence of H<sub>2</sub>O<sub>2</sub>.

**Phosphatase.** Phosphatase enzymes catalyse the hydrolysis of phosphate esters. Milk contains an acid and alkaline phosphatase. Alkaline phosphatase has a pH optimum near 9 and is inactivated by heating milk to 72°C for 15 seconds. Its absence indicates that milk has been properly pasteurised. If milk is inadequately pasteurised, the residual enzyme will catalyse the hydrolysis of added disodium para-nitro-phenol phosphate liberating para-nitro-phenol which is yellow in alkaline solution. Acid phosphatase which has a pH optimum of 4, is more heat stable than alkaline phosphatase.

**Other milk enzymes.** Milk also contains lipases (discussed earlier under hydrolytic rancidity) proteases, amylases, xanthine oxidase, carbonic anhydrase and lysozyme.

### 4.3.3 Carbohydrates

Lactose is the major carbohydrate fraction in milk. It is a disaccharide composed of two sugars, glucose and galactose (Figure 6). The average lactose content of milk varies between 4.7 and 4.9%, although milk from individual cows may vary more. Mastitis reduces lactose secretion.

Lactose is a source of energy for the young calf and provides 4 calories/g of lactose metabolised. It is less soluble in water than sucrose and is also less sweet. It can be broken down to glucose and galactose by bacteria that have the enzyme ß-galactosidase. The glucose and galactose can then be fermented to lactic acid. This occurs when milk goes sour. Under controlled conditions they can also be fermented to other acids to give a desired flavour, such as propionic acid fermentation in Swiss-cheese manufacture.



Lactose is present in milk in molecular solution. In cheesemaking, almost all of the lactose remains in the wheyfraction. It has been recovered from whey for use in the pharmaceutical industry, where its low solubility in water makes it suitable for coating tablets. It is also used to fortify baby-food formulations. Lactose can be sprayed on silage to increase the rate of acid development in silage fermentation. It can be converted into ethanol using certain strains of yeast; the yeast biomass is recovered and used as animal feed.

However, these processes are expensive and a large through put is necessary for them to be profitable. For smallholders, whey is best used as a food for humans and animals without any further processing.

Heating milk above  $100^{\circ}$ C causes lactose to combine irreversibly with the milk proteins. This reduces the nutritional value of the milk and also turns it brown.

Because lactose is not as soluble in water as sucrose, adding sucrose to milk forces lactose out of solution and it crystallises. This causes sandiness in such products as ice cream. Special processing is required to crystallise lactose when manufacturing products such as instant skim milk powders.

In addition to lactose, milk contains traces of glucose and galactose. Carbohydrates are also present in association with protein. K-casein, which stabilises the casein system, is a carbohydrate-containing protein.

### 4.3.4 Minor milk constituents

In addition to the major constituents already discussed, milk also contains a number of organic and inorganic compounds in small or trace amounts, some of which affect both the processing and nutritional properties of milk.

#### Milk salts

The salts of milk are composed mainly of the chlorides, phosphates, citrates, carbonates and bicarbonates of sodium, potassium, calcium and magnesium. Approximately 20 other elements are found in milk in trace amounts. These include copper, iron, lead, boron, manganese and iodine. Milk salts are important in human nutrition, stability of milk lipids and in the processing of milk proteins.

The ash content of cow milk remains relatively constant at 0.7 to 0.8%, but the relative concentrations of the various ions vary considerably. The composition is influenced by a number of factors including breed, individuality of the cow, stage of lactation, feed, infection of the udder and season of the year. Certain milk salts, e.g. sodium and potassium chlorides are sufficiently soluble to be present almost in the dissolved phase. The content of others, in particular calcium phosphate, is greater than can be maintained in solution at the normal pH of milk. Consequently, these exist partly in soluble form and partly in insoluble or colloidal form. Table 6 gives some data on the partition of salts between the two phases.

	Total	Dissolved	Colloidal			
Salt		(mg/100 ml of milk)				
Calcium	132.1	51.8	80.3			
Magnesium	10.8	7.9	2.9			
Total phosphorus	95.8	36.3	59.5			
Citrate	156.6	141.6	15.0			

**Table 6.** Distribution of milk salts between the soluble and colloidal phases.

#### Milk vitamins

Milk contains the fat-soluble vitamins A, D, E and K in association with the fat fraction and water-soluble vitamins B complex and C in association with the water phase. Vitamins are unstable and processing can therefore reduce the effective vitamin content of milk. The stability of some vitamins is given in Table 7.

Tuble 1. Stability of vitaminis.					
Vitamin	Heat	Light	Air	Alkali	Acid
А	FS	U	U	S	FS
С	U	U	U	U	S
Thiamin	U	S	FS	U	S
B <sub>2</sub>	FS	S	S	U	S
Tocopherols (E)	U	U	U	S	S
Folic acid	U	U	U	S	U

Table 7.	Stability	of vitamins.
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S = stable; U = unstable; FS = fairly stable.

# 5. Microbiology

Micro-organism is the term applied to all microscopic living organisms. Micro-organisms tend to be associated with disease; those that cause disease are called pathogens. However, few micro-organisms are pathogens and micro-organisms play a crucial part in life on our planet. For example they provide food for fish, they occur in soil where they provide nutrients for plants and they play an important role in ruminant digestion.

In dairying some micro-organisms are harmful, e.g. spoilage organisms and pathogens while others are beneficial, e.g. cheese and yoghurt starters and yeasts and moulds used in controlled fermentations and cheesemaking.

The micro-organisms principally encountered in the dairy industry are bacteria, yeasts, moulds and viruses.

# 5.1 Bacteria

Bacteria are microscopic single-celled organisms that are present in air, water and on most solid materials. When observed under a microscope the cells can be seen to differ in shape and in conformation of groups of cells. Cells are either spherical or rod-shaped (Figure 7); spherical bacteria are called cocci while those that are rod-shaped are called bacilli. This is the first basis for differentiating between bacterial cells.

Figure 7. Rod-shaped (bacilli) and spherical (cocci) bacteria.



Bacteria are also classified according to cell-cluster formation:

- Diplococci: paired cocci cells.
- Staphylococci: a number of cells clustered together.
- Streptococci: a number of cells arranged in a chain.

Some bacteria are motile. They move using flagellae—long, hair-like appendages growing out of the cell. Some rod-shaped bacteria may form spores when the cells are faced with adverse conditions such as high temperature. Once suitable conditions are re-established the spores germinate to form new cells.

Close examination of the simple cell reveals that it is composed of the following components (Figure 8):

- cell wall which gives the cell its shape and retains the constituents
- cell membrane for filtering in food constituents and discharging waste products
- nucleus where the genetic material of the cell is stored. The cytoplasm is a semi-liquid proteinaceous substance which contains starch, fat and enzymes.





The cell membrane is semi-permeable and allows the cell to feed by osmosis, i.e. the exchange of nutrients between the cytoplasm of a living cell and the surrounding aqueous material. Only small molecules can pass in and out of the cell, e.g. with a sugar solution on one side of a semi-permeable membrane and water on the other, water will diffuse in, diluting the sugar solution. The sugar molecules cannot pass out so a hydrostatic pressure, known as osmotic pressure, develops.

Bacteria feed by selective intake of nutrients dissolved in water. They can also take in nutrients against the normal osmotic flow, a process called active transport.

### 5.1.1 Bacterial growth

Bacterial growth refers to an increase in cell numbers rather than an increase in cell size. The process by which bacterial cells divide to reproduce themselves is known as binary transverse fission. The time taken from cell formation to cell division is called the generation time which can be defined as the time taken for the cell count to double.

Figure 9 shows the phases of bacterial growth following inoculation of bacteria into a new growth medium.

Figure 9. The four phases of bacterial growth.



The following phases can be identified:

- 1. *Lag phase*: There is usually some delay in growth after inoculation of bacteria into a new medium. During this time the bacteria adapt to the medium and synthesise the enzymes needed to break down the substances in it.
- 2. Log phase: Once the bacteria have adapted to the new medium they start to reproduce quickly and their numbers multiply evenly for each increment of time. Plotting the log number of cells against time gives a linear relationship; this is therefore called the log phase. The cells are at their greatest activity in this phase. Transferring cultures to a fresh medium at regular intervals can maintain the cells in an active state. An active culture can rapidly dominate any new environment. This phase can be prolonged by removing toxic waste, adding more nutrients or both.
- Stationary phase: As the bacteria dominate the growth medium they deplete the available nutrients and toxic waste products accumulate, slowing the rate of reproduction. At the same time, cells are dying off. A state of equilibrium is reached between the death of old cells and formation of new ones resulting in no net change in cell numbers.
- 4. Death phase: In this phase the formation of new cells ceases and the existing cells gradually die off.

# 5.1.2 Factors affecting bacterial growth

Bacterial growth is affected by temperature, nutrient availability, water supply, oxygen supply, and acidity of the medium.

#### Temperature

Theoretically, bacteria can grow at all temperatures between the freezing point of water and the temperature at which protein or protoplasm coagulates. Somewhere between these maximum and minimum points lies the optimum temperature at which the bacteria grow best.

Temperatures below the minimum stop bacterial growth but do not kill the organism, however, if the temperature is raised above the maximum, bacteria are soon killed. Most cells die after exposure to heat treatments of 70°C for 15 seconds, although spore-forming organisms require more severe heat treatment, e.g. live steam at 120°C for 30 minutes.

Bacteria can be classified according to temperature preference. Psychrotrophic bacteria grow at temperatures below 16°C, mesophilic bacteria grow best at temperatures between 16 and 40°C, and thermophilic bacteria grow best at temperatures above 40°C.

#### Nutrients

Bacteria need nutrients for their growth and some need more nutrients than others. Lactobacilli live in milk and have lost their ability to synthesise many compounds, while *Pseudomonas* can synthesise nutrients from very basic ingredients.

Bacteria normally feed on organic matter which contains both material for cell formation and the necessary energy. The organic matter must be soluble in water and of low molecular weight to be able to pass through the cell membrane. Bacteria therefore need water to transport nutrients into the cell.

If the nutrient material is not sufficiently broken down, the micro-organism can produce exo-enzymes which split the nutrients into smaller, simpler components so they can enter the cell. Inside the cell the nutrients are broken down further by other enzymes, releasing energy which is used by the cell.

#### Water

Bacteria cannot grow without water. Many bacteria are quickly killed by dry conditions, although others can tolerate such conditions for months; bacterial spores can survive dry conditions for years. Water activity (Aw) is used as an indicator of the availability of water for bacterial growth. Distilled water has an Aw of 1. Addition of solute, e.g. salt reduces the availability of water to the cell and the Aw drops; at Aw less than 0.8 cell growth is reduced. Cells that can grow at low Aw are called osmophiles.

#### Oxygen

Animals require oxygen to survive but bacteria differ in their requirements for and in their ability to utilise oxygen.

Aerobic bacteria need oxygen for growth, however, it is toxic to anaerobic bacteria. Anaerobic organisms are responsible for reactions such as methane production in biogasplants and spoilage in canned foods and cheeses. Some bacteria can live either with or without oxygen and are known as facultative anaerobic bacteria.

#### Acidity

The acidity of a nutrient substrate is most simply expressed as its pH value. Sensitivity to pH varies from one species of bacteria to another. The terms pH optimum and pH maximum are used. Most bacteria prefer a growth environment with a pH of about 7, i.e. neutrality.

Bacteria that can tolerate low pH are referred to as aciduric. Lactic acid bacteria in milk produce acid and continue to do so until the pH of the milk falls below 4.6, at which point they gradually die off.

#### 5.1.3 Bacteria in milk

Milk fresh from a healthy cow contains few bacteria, but contamination during handling can rapidly increase bacterial numbers. Milk is an ideal food and many bacteria grow readily in it.

Some bacteria (lactic acid bacteria) are useful in milk processing, causing milk to sour naturally, leading to fermented products such as *irgo*. However, milk can also contain pathogenic bacteria, such as *Salmonella, Mycobacterium tuberculosis, Listeria* and *Brucella*, and can thus transmit disease. Other bacteria can cause spoilage of the milk, and spoilage and poor yields of products.

# 5.2 Moulds

Moulds are a heterogeneous group of multicelled organisms which reproduce asexually either by spore formation or by fragmentation. They can grow on a wide variety of substrates and are generally regarded as spoilage organisms. However, moulds are used in the production of antibiotics and in certain cheese varieties. Moulds are aerobic organisms and their growth on foods can be retarded by excluding air through careful packaging. They can be killed by relatively mild heat treatments, but mould spores are more resistant to heat. The structure of moulds is shown in Figure 10.



# 5.3 Yeasts

Yeasts are unicellular organisms which reproduce asexually by budding. They are used industrially to ferment carbohydrates to such products as alcohol and citric acid. Yeasts are not usually used in milk processing and are normally regarded as spoilage organisms in dairy products. The structure of yeasts is shown in Figure 11.

Figure 11. Structure of a yeast cell.



# 5.4 Viruses

Viruses are extremely small organisms comprising a spherical head containing the genetic material, and a cylindrical tail. They must invade other cells to reproduce. Viruses that attack bacterial cells are known as bacteriophages. Bacteriophages that attack acid-producing bacteria inhibit acid production in milk thereby causing problems in the manufacture of fermented milks, yoghurt and cheese.

# 5.5 Milk microbiology

In addition to being a nutritious food for humans, milk provides a favourable environment for the growth of micro-organisms. Yeasts, moulds and a broad spectrum of bacteria can grow in milk, particularly at temperatures between 16 and  $35^{\circ}$ C.

Microbes can enter milk via the cow, air, feeds, milk handling equipment and the milker. Once micro-organisms get into the milk their numbers increase rapidly. It is more effective to exclude micro-organisms than to try to control microbial growth once they have entered the milk. Bacterial types commonly associated with milk are given in Table 8.

Milking equipment should be washed thoroughly before and after use — rinsing is not enough. Microbial growth can be controlled by cooling the milk as most micro-organisms reproduce slowly in colder environments. Cooling milk also slows chemical deterioration.

The temperature of freshly drawn milk is about  $38^{\circ}$ C. Bacteria multiply very rapidly in warm milk and milk sours rapidly if held at these temperatures. If the milk is not cooled and is stored in the shade at an average air temperature of 16°C, the milk temperature will only have fallen to 28°C after three hours. Cooling the milk with cold running water will reduce the temperature to 16°C after one hour. At this temperature bacterial growth will be reduced and enzyme activity retarded. Thus, milk will keep longer if cooled (see Table 9).

Natural souring of milk may be advantageous, e.g. in smallholder buttermaking the acid developed assists in the extraction of fat during churning. The low pH retards growth of lipolytic and proteolytic bacteria and therefore protects the fat and protein in the milk and it also inhibits the growth of pathogens. The acidity does not, however, retard the growth of moulds.

Bacteria	Effect on milk
Pseudomonas	Spoilage
Brucella	Pathogenic
Enterobacteriaceae	Pathogenic and spoilage
Staphylococci	
Staphylococcus aureus	Pathogenic
Streptococcus	
S. agalactiae	Pathogenic
S. thermophilus	Acid fermentation
Lactococci	
L. lactis	Acid fermentation
L. lactis-diacetylactis	Flavour production
L. cremoris	Acid fermentation
Leuconostoc lactis	Acid fermentation
Bacillus cereus	Spoilage
Lactobacillus	
L. lactis	Acid production
L. bulgaricus	Acid production
L. acidophilus	Acid production
Propionibacterium	Acid production
Mycobacterium tuberculosis	Pathogenic

 Table 8.
 Bacterial types commonly associated with milk.

Naturally soured milk is used to make many products, e.g. *irgo*, yoghurt, sour cream, ripened buttermilk and cheese. These products provide ways of preserving milk and are also pleasant to eat. They are produced by the action of fermentative bacteria on lactose and are more readily digested than fresh milk.

The initial microflora of raw milk directly reflects microbial contamination during production. The microflora in milk when it leaves the farm is determined by the temperature to which it has been cooled and the temperature at which it has been stored.

The initial bacterial count of milk may range from less than 1000 cells/ml to  $10^6$  cells/ml. High counts (more than  $10^5$  cells/ml) are evidence of poor production hygiene. Rapid tests are available for estimating the bacterial quality of milk (see Chapter 10).

### 5.5.1 Pasteurisation

Pasteurisation is the most common process used to destroy bacteria in milk. In pasteurisation, the milk is heated to a temperature sufficient to kill pathogenic bacteria, but well below its boiling point. This also kills many non-pathogenic organisms and thereby extends the storage stability of the milk.

Numerous time/temperature combinations are recommended but the most usual is 72°C for 15 seconds followed by rapid (less than 2 minutes) cooling to below 10°C. This is normally referred to as High Temperature Short Time (HTST) treatment. It is carried out as a continuous process using a plate heat-exchanger to heat the milk and a holding section to ensure that the milk is completely pasteurised. Milk is normally pasteurised before sale as liquid milk. Pasteurisation is used to reduce the microbial counts in milk for cheesemaking, and cream is pasteurised before tempering for buttermaking in some factories.

Batch pasteurisation is used where milk quantities are too small to justify the use of a plate heat-exchanger. In batch pasteurisation, fixed quantities of milk are heated to  $63^{\circ}$ C and held at this temperature for 30 minutes. The milk is then cooled to  $5^{\circ}$ C using iced or cold water before packing.

The lower temperature used for batch pasteurisation means that a longer time is required to complete the process -30 minutes at 63°C, compared with 15 seconds at 72°C.

#### Effects of pasteurisation on milk

Pasteurisation reduces the cream layer, since some of the fat globule membrane constituents are denatured. This inhibits clustering of the fat globules and consequently reduces the extent of creaming. However, pasteurisation does not reduce the fat content of milk.

Pasteurisation has little effect on the nutritive value of milk as the major nutrients are not altered. There is an insignificant loss of vitamin C and the B group vitamins.

The process kills many fermentative organisms as well as pathogens but putrefactive micro-organisms survive pasteurisation. Although pasteurised milk has a storage stability of two to three days, subsequent deterioration is caused by the putrefactive organisms. Thus, pasteurised milk will putrefy rather than develop acidity.

In rural milk processing, many processes depend on the development of acidity, and hence pasteurisation may not be appropriate.

### 5.5.2 Sterilisation

In pasteurisation, milk receives mild heat treatment to reduce the number of bacteria present. In sterilisation, milk is subjected to severe heat treatment that ensures almost complete destruction of the microbial population. The product is then said to be commercially sterile. Time/temperature treatments of above 100°C for 15 to 40 minutes are used. The product has a much longer shelf-life (several months) than pasteurised milk.

Another method of sterilisation is ultra high temperature treatment (UHT). In this system, milk is heated under pressure to about 140°C for 4 seconds. The product is sterile, however, it retains more of the properties of fresh milk than conventionally sterilised milk.

# 5.6 Microbiology of butter

Butter is made as a means of preserving milk fat. It can be made directly from milk or by separation of milk and subsequent churning of the cream.

### 5.6.1 Sources of contamination

In addition to bacteria present in the milk other sources of micro-organisms in butter are equipment, wash water, air, packing materials and personnel.

#### Equipment

In smallholder buttermaking, microbial contamination can come from unclean surfaces, the butter maker and wash water. Packaging materials, cups and leaves are also sources of contaminants. Washing and smoking the churn reduces bacterial numbers. However, traditional equipment is often porous and is therefore a reservoir for many organisms.

When butter is made on a larger processing scale, bacterial contamination can come from holding-tank surfaces, the churn and butter-handling equipment.

A wooden churn can be a source of serious bacterial, yeast and mould contamination since these organisms can penetrate the wood, where they can be destroyed only by extreme heat. If a wooden churn has loose bands, cream can enter the crevices between the staves, where it provides a growth medium for bacteria which contaminate subsequent batches of butter.

However, if care is taken in cleaning a wooden churn this source of contamination can be controlled. Similar care is required with scotch hands (wooden spatulas) and butter-working equipment.

#### Wash water

Wash water can be a source of contamination with both coliform bacteria and bacteria associated with flavour defects in butter. Polluted water supplies can also be a source of pathogens.

#### Air

Contamination from the air can introduce spoilage organisms; mould spores, bacteria and yeasts can fall on the butter if it is left exposed to the air. Moulds grow rapidly on butter exposed to air.

#### Packaging

Care is required in the storage and preparation of packaging material. Careless handling of packaging material can be a source of mould contamination.

#### Personnel

A high standard of personal hygiene is required from people engaged in buttermaking. For example in New Zealand the 1938 dairy produce regulations stated "no person shall permit his bare hands to be brought in contact with any butter at any time immediately following manufacture or during the wrapping, packaging, storage and transport of such butter."

Personnel pass organisms on to butter via the hands, mouth, nasal passages and clothing. Suitable arrangements for cleaning and disinfecting hands should be provided, and clean working garments should not have contact with other clothes.

### 5.6.2 Control of micro-organisms in butter

Salting effectively controls bacterial growth in butter. The salt must be evenly dispersed and worked in well. A salt concentration of 2% adequately dispersed in butter with 16% moisture will result in a 12.5% salt solution throughout the water-in-oil emulsion.

Washing butter does little to reduce microbiological counts. It may be desirable not to wash butter, since washing reduces yield by removing curd or protein material. The acid pH of serum in butter made from ripened cream or sour milk may control the growth of acid-sensitive organisms.

Microbiological analysis of butter usually includes some of the following tests: total bacterial count, yeasts and moulds, coliform estimation and estimation of lipolytic bacteria. Yeast, mould and coliform estimations are useful for evaluating sanitary practices. The presence of defect-producing types can be indicated by estimating the presence of lipolytic organisms.

All butter contains some micro-organisms. However, proper control at every stage of the process can minimise their harmful effects.
# 6. Clean milk production

Milk is one of the most valuable foods for humans and young mammals. It also provides an excellent medium for the growth of bacteria which may spoil the milk or render it unsafe for human consumption or unfit for further processing. There is a constant challenge to those involved in milk production to prevent or minimise the entry and subsequent growth of bacteria in milk. Milk of good hygienic quality is necessary to produce milk products of good quality and adequate shelf-life and to provide a safe, wholesome food for the consumer.

# 6.1 Sources of contamination

## 6.1.1 The interior of the udder

At one time it was generally accepted that milk as it was removed from the udder contained no bacteria. It has subsequently been shown that the normal udder contains bacteria which enter the milk as soon as it is secreted. The number of bacteria in aseptically drawn milk varies from animal to animal and even from different quarters of the same animal. On average, aseptically drawn milk from healthy udders contains between 500 and 1000 bacteria/ml. Infected udders usually yield milk with very high counts. The fore milk contains many bacteria but numbers decrease during milking. This decrease is due to mechanical dislodgement of the bacteria particularly in the teat canal.

The species of bacteria found in milk as it comes from the udder are limited to a few genera. The micrococci are generally present in the greatest proportion followed by streptococci and rods. Micrococci are comparatively slow growing but if allowed to grow in milk they cause proteolysis (protein breakdown) and acid formation resulting in a very distasteful product. The streptococci in uninfected udders occur less frequently than the micrococci but they are more important owing to their action in milk.

*Streptococcus agalactiae* is the organism commonly present even when there is no clinical evidence of mastitis. The number of *S. agalactiae* increases before the time the udder shows inflammation and persists after the recovery of the animal from active mastitis. This organism is not pathogenic to humans and is killed by pasteurisation ( $72^{\circ}$ C for 15 seconds).

## 6.1.2 The cow as a source of pathogens

There are various pathogens that may be present in the milk of infected cows many of which can cause illness to humans. Fortunately, the incidence of disease transmitted by milk has been greatly reduced by better husbandry, disease prevention and eradication programmes and better sanitation methods of milk production.

Mastitis infections may result in large numbers of bacteria in milk. Mastitis is caused by *Streptococcus pyogenes* or *Staphylococcus aureus* which constitute a health hazard to consumers. *Brucella abortus* is found in the milk of cows suffering from the disease brucellosis. This disease is very infectious and is the cause of contagious abortion in cattle and undulant fever in humans. Tuberculosis, caused by *Mycobacterium tuberculosis*, is another disease that may occur in cattle and which may be transmitted to humans who drink raw milk.

The exterior of the udder can be a major source of bacterial contamination to milk. Cleaning and removal of soil, bedding material and manure from the udder and flanks of the cow before milking is necessary to prevent the entry of many types of bacteria into the milk. Special care must be given to the cloths used for cleaning the udder. The re-use of cloths for cleaning and sanitising may result in re-contamination of the udder. It is therefore recommended that separate cloths be used for cleaning and sanitising and, if possible, each cloth should be used for one cow only. Clipping and grooming the udder and flanks makes cleaning and sanitising more effective.

In addition to the exterior of the udder, the cow's coat may also serve as a vehicle of contamination by adding bacteria directly to the milk during milking. The coat may carry bacteria from stagnant pools of water and muddy grazing areas. Coliform bacteria and members of the genus *Bacillus* may enter the milk from soil

and manure adhering to the coat of the cow. The presence of such organisms in milk is undesirable as they may cause off flavours and a reduction in the quality and shelf-life of milk and milk products. Periodic clipping in addition to daily washing and brushing the coat are recommended practices in the production of milk of good hygienic quality.

# 6.1.3 Milking utensils

Utensils used for milking and handling milk can be a most important cause of milk contamination. Increased mechanisation of milking, handling and storage has contributed significantly to the production of clean milk. However, it has been shown that where milking equipment, milk pipelines and storage tanks are improperly cleaned and maintained the hygienic quality of the milk is worse than that obtained through manual milking and handling. It is important, therefore, that milking and milk handling utensils are properly cleaned and maintained. An effective cleaning procedure for milk handling equipment is given in Chapter 9.

# 6.1.4 Miscellaneous sources of bacteria in milk

Micro-organisms occur in the air and in dust particles originating from manure, soil and feed. Conditions that increase the dust content in the air around the milking area will increase the microbial population and lead to increased bacterial contamination of the milk particularly where hand milking is practised. To reduce the dust content of the air the following practices should be avoided:

- sweeping the milking area before milking
- handling hay and feeds before and during milking
- brushing the cow immediately before milking
- dusty bedding
- accumulation of dirt and dust on the walls and ceiling.

The milking barn or area must be kept clean and, to facilitate cleaning, the floors and walls should be constructed of smooth-surfaced concrete or other impervious material. Adequate lighting is needed to carry out milking and cleaning operations satisfactorily and proper ventilation is required in the milk house to avoid condensation on the walls and ceiling. Flies, insects and rodents must be kept out of the milking house since their presence on milking equipment contributes not only to the total bacteria entering milk but also to the possibility that pathogens may be introduced. The milk house should have screened doors and windows.

The health of milkers and personnel handling milk is of considerable importance. These people should be in good health and their hands free from any infections. Hands with infected wounds can add pathogenic streptococci or micrococci to milk and cause subsequent human infections. Wet-hand milking is also discouraged.

Milk may serve as a carrier of human pathogens from one person to another. Typhoid and paratyphoid fever, dysentery, scarlet fever, septic sore throat, diptheria and cholera have been found to be milk-borne and to enter the milk from infected workers.

# 6.2 Cooling milk

To prevent or retard growth of bacteria in milk and to maintain its quality for domestic consumption or during transport to the processing plant, it is essential to cool the fresh milk as quickly as possible. The temperature to which milk can be cooled on the farm will depend on the facilities available. If mechanical refrigeration is available then the milk can be cooled to  $3-4^{\circ}C$  and the frequency of delivery to the processing plant need be no more than three times a week. However, refrigeration does not reduce bacteria numbers it only slows down their growth. Some bacteria (psychrotrophs) are capable of growing at low temperatures so the importance of limiting contamination of milk by unclean utensils, poor water supplies, unhealthy cows and general unhygienic milking practices and conditions is further emphasised.

In the absence of mechanical cooling facilities other means of cooling milk to the lowest possible temperature must be employed. In some situations water supplies may be inadequate so the milk container should be placed in a cool, shaded area. The milk can may be placed in a trough of cool water or in a stream.

It may also be placed in a box or cabinet surrounded with sacking material and a layer of sand or charcoal. At high ambient temperatures the temperature of the cooling box and therefore of the milk can and its contents can be reduced to about 20°C by spraying the outside of the box with water. The evaporation of the water (evaporative cooling) reduces the temperature within the cooling box. Other methods of cooling milk which require large quantities of water include in-can coolers and surface coolers. In both cases cold water passes through metal tubes giving indirect contact with the milk outside the metal tubes. Whatever method of milk cooling is employed the fresh milk should be cooled quickly to the lowest possible temperature.

Table 9 shows the effect of temperature on the growth of bacteria in milk which has been produced under various conditions.

Production	Storage	Bacterial numbers ('000) per ml		
conditions	temperature (°C)	Fresh	24 hrs	48 hrs
1. Clean cows	4.5	4	4	4.6
Clean environment and	10.0	4	14	128
Clean utensils	15.5	4	1600	33 000
2. Clean cows	4.5	39	88	122
Dirty environment and	10.0	39	180	832
Dirty utensils	15.5	39	4500	99 100
3. Dirty cows	4.5	136	282	540
Dirty environment and	10.0	136	1200	13 700
Dirty utensils	15.5	136	24 700	640 000

Table 9.	Effect of temperature of	i the growth of	f bacteria in milk	produced under	different conditions
	r			r	

Summary of important points in the production of clean milk from healthy cows:

- 1. Udder washing. Before milking, the udder should be washed with clean water. A clean cloth or, if possible, disposable towels should be used.
- 2. Use of strip cup. A strip cup should be used to check for mastitis in each quarter before milking starts. This will prevent mixing mastitic milk with good milk.
- 3. Milking. The body of the cow should be free of soil, dirt and manure and contamination of milk from external sources such as animal hairs, dust, flies and dirty water dripping from the cow's body should be minimised. Avoid using dusty bedding and avoid feeding animals during milking. Milking equipment should be clean and well maintained.
- 4. Milkers. Milkers and milk handlers should be in good health and their hands should be clean and free from cuts and sores.
- 5. Milk house. The milking barn should have a good floor that is easy to clean and drain. There should be good ventilation and lighting and facilities for manure disposal and washing cows. A good supply of clean water is required.
- 6. Cooling milk. Cooling milk is essential to prevent an increase in bacterial numbers and spoilage of the milk.

# 7. Milk reception, dairy accounting and record keeping

# 7.1. Reception

When milk is brought from the farm to the dairy for processing the following information on the milk is required:

- Quality
- Quantity
- Composition
- Presence of contaminants neutralisers, preservatives etc
- Presence of added water.

# 7.1.1. Quality

Before weighing the milk, its quality should be checked. Taste and smell are good preliminary indicators of milk quality, and visual observation can also be useful. If the person receiving the milk suspects that it is of poor quality, he or she can carry out one of the following tests: acidity, pH, alcohol and clot-on-boiling. These will determine the quality of the milk. Once the person receiving the milk is satisfied with its quality, it can be weighed and the weight recorded.

# 7.1.2 Quantity

The quantity of milk received can be estimated either volumetrically or gravimetrically. Milk processors usually base payments for milk on its solids content, and hence it is more appropriate to use weight to estimate the quantity of milk being tendered.

In a small-scale processing centre a spring balance on a tripod and a stainless-steel bucket can be used to weigh milk. Milk weight must be recorded accurately as losses to either the seller or buyer can be incurred if care is not taken at this stage.

# 7.1.3. Composition of milk

A dairy whose principal product is butter should base its payments on the butterfat content of the milk. The milk received will therefore have to be sampled and analysed for butterfat content. It is expensive to analyse all individual milk supplies for butterfat content on a daily basis. It is suggested that all milk supplies be sampled on a daily basis and a composite sample of these daily samples is tested once or twice a month. The composite sample is maintained in good condition by using a permitted preservative such as potassium dichromate.

If payment for milk is made on the basis of total solids content the following tests can be carried out:

- 1. The most accurate way to determine the total solids (TS) content of milk is by evaporating the water from an accurately weighed sample using a drying oven.
- 2. A less laborious and less expensive method is to use a lactometer to determine the specific gravity of the milk and calculate the TS using a recognised formula (see Chapter 10).

# 7.1.4 Adulteration of milk

There are several ways in which milk may be adulterated, e.g. by adding water to increase the quantity of milk delivered and by adding an alkali to reduce the acidity of the milk with the intention to mislead with regard to its freshness. A milk supplier may also skim off a portion of the cream layer and retain it for domestic purposes. Sophisticated equipment and techniques are required to precisely determine the degree and type

of adulteration but the results of fat, titratable acidity and specific gravity tests may give strong indications of fraudulent behaviour by the milk supplier. If a lower than normal fat test is obtained combined with a high (1.035) specific gravity then milk skimming should be suspected. If a lower than normal fat test is obtained combined with a low (1.020) specific gravity then the addition of water should be suspected. A lower than normal titratable acidity, e.g. 0.10% lactic acid suggests the addition of an alkali such as sodium hydroxide or sodium bicarbonate.

# 7.2 Dairy accounting and record keeping

# 7.2.1 Milk quantity and quality

Where smallholders are supplying milk to a central processing unit it is necessary to obtain and maintain accurate details of milk supplies, milk quality and payments for the milk. When the milk is delivered to the processing unit it is necessary to obtain the weight or the volume of the milk and it is also necessary to sample the milk to determine its hygienic and compositional quality. The hygienic quality can be determined by means of microbiological and dye reduction tests and the compositional quality may be ascertained by measuring the fat, protein and total solids content.

Different methods of payment may be used. The smallholder may be paid on the basis of the amount of milk, butterfat or total solids delivered. Incorporated in the milk payment scheme may be bonuses or penalties for milk of different microbiological standards. All milk quality payment schemes should be designed to offer an incentive to smallholders to produce better quality milk.

To simplify keeping data concerning the amount and quality of milk supplies each supplier should be assigned a code or a number. A register containing the supplier's name and code or number should be kept at the processing centre.

Payment to milk suppliers is sometimes made daily or weekly but is generally made on a monthly basis. Whatever the payment period all computations must be based on accurate records obtained from accurate and reliable sampling and testing.

While it is advocated that strict control should be exercised over the quality of milk supplies, the economics and practicality of quality schemes must be kept in mind. If the cost of implementing a quality payment scheme outweighs the gains obtained from producing a better quality product then such payment schemes should be carefully reconsidered.

# 7.2.2 Processing records

Maintaining proper records of milk processing enables the processor to identify whether the operation is efficient in terms of time, product composition and raw materials used. It should be emphasised that common sense should be applied as to the amount and type of records that should be kept. Proper interpretation of the recorded data is extremely important and the accumulation of large amounts of data does not indicate an efficient manufacturing operation.

# 7.2.3 Records of product quality and sales

It is the objective of every milk-processing enterprise to operate an efficient and profitable unit.

Apart from milk payment and processing records it is also necessary to keep records of the quality and amount of products sold. To comply with statutory and consumer standards it is necessary to obtain and keep records pertaining to these quality standards, e.g. fat content of milk, moisture content of butter.

Records of sales and payment for these sales must be kept. An appropriate record sheet for each particular product will assist in identifying trends in product movement to enable processing strategies (the amount and type of product) to be drawn up.

Proper accounting and record keeping is an essential part of every milk-manufacturing operation. Accounts and records are necessary to monitor quality and quantity of raw materials and the overall efficiency and profitability of the enterprise.

# 7.2.4 Suggested formats for records of milk intake, payment and utilisation

#### Daily milk intake

(a) Month Milk received,	Yea	ır				
Supplier no.	01	02	03	04	05	06 etc
Date						
1						
2						
3						
etc						
Totals						

(b)	Supplier no.	Month	Year
-----	--------------	-------	------

Date	Milk received, kg	Fat, %	Total solids, %
1			
2			
3			
etc			
	Total	Average	Average

The fat and total solids determinations need not be carried out daily. Instead the milk supply is sampled daily to make a composite sample which is tested once or twice in the month.

## Milk payments record

(a) Month\_\_\_\_\_Year \_\_\_\_

Supplier no.	Milk delivered, kg	Fat, %	Fat/kg	Price/kg	Total
01					
02					
03					
etc					

(b) Month \_\_\_\_\_ Year\_\_\_\_

Supplier no.	Milk delivered, litre	Price/litre	Total
01			
02			
03			
etc			

#### **Record of total milk supplies**

Month\_\_\_\_\_Year\_\_\_\_

Date	Milk received, kg	Fat, %	Fat, kg	Total solids, %	Total solids, kg
1					
2					
3					
etc					
	Total	Average	Total	Average	Total

#### Milk utilisation

Month\_\_\_\_\_Year\_\_\_\_

Date	Milk received, kg	Cream, kg	Cheesemaking, kg	Skim, kg
1				
2				
3				
etc				
Totals				

#### **Record of butter manufacture**

Month\_\_\_\_\_Year\_\_\_\_

Date	Butter produced, kg	Moisture %	Fat %	Produce	Overrun
1					
2					
3					
etc					

# 8. Milk processing

In rural areas, milk may be processed fresh or sour. The choice depends on available equipment, product demand and on the quantities of milk available for processing. In Africa, smallholder milk-processing systems use mostly sour milk. Allowing milk to ferment before processing has a number of advantages and processing sour milk will continue to be important in this sector.

Where greater volumes of milk can be assembled, processing fresh milk gives more product options, allows greater throughput of milk and, in some instances, greater recovery of milk solids in products.

Equipment not available locally, such as a milk separator, has a cost advantage and quickly gives a good financial return in terms of increased efficiency. Hand-operated milk separators are durable and have a long life when properly maintained. Importing of such equipment is, therefore, advantageous.

In many rural dairy processing plants monitoring equipment may not be available and, although yields may be maximised by adhering to the prescribed procedures, all these products can be successfully made by approximating temperature, time, pH etc. It is particularly important in cheesemaking to proceed when the curd is in a suitable condition. Therefore, times given are only approximate and the processor will, with experience, adopt methods suitable to his/her own environment.

# 8.1 Milk separation

The fat fraction separates from the skim milk when milk is allowed to stand for at least 30 to 40 minutes. This is known as "creaming". The creaming process can be used to remove fat from milk in a more concentrated form. A number of methods are employed to separate cream from milk. An understanding of the creaming process is necessary to maximise the efficiency of the separation process.

## 8.1.1 Gravity separation

Fat globules in milk are lighter than the plasma phase, and hence rise to form a cream layer. The rate of rise (V) of the individual fat globule can be estimated using Stokes' Law which defines the rate of settling of spherical particles in a liquid:

$$V = \frac{r^2(d_1 - d_2) g}{9n}$$

where :

r = radius of fat globules

 $d_1$  = density of the liquid phase

 $d_2$  = density of the sphere

g = acceleration due to gravity

n = specific viscosity of the liquid phase

- Particle  $r^2$ : As temperature increases, fat expands and therefore  $r^2$  increases. Since the sedimentation velocity of the particle increases in proportion to the square of the particle diameter, a particle of radius 2 ( $r^2=4$ ) will settle four times as fast as a particle of radius 1 ( $r^2=1$ ). Thus, heating increases sedimentation velocity.
- d<sub>1</sub>-d<sub>2</sub>: Sedimentation rate increases as the difference between d<sub>1</sub> and d<sub>2</sub> increases. Between 20 and 50°C, milk fat expands faster than the liquid phase on heating. Therefore, the difference between d<sub>1</sub> and d<sub>2</sub> increases with increasing temperature.
- g: Acceleration due to gravity is constant. This will be considered when discussing centrifugal separation.
- n: Serum viscosity decreases with increasing temperature.

Calculation of the sedimentation velocity of a fat globule reveals that it rises very slowly. As shown in the equation, the velocity of rise is directly proportional to the square of the radius of the globule. Larger globules overtake smaller ones quickly. When a large globule comes into contact with a smaller globule the two join and rise together even faster, primarily because of their greater effective radius. As they rise they come in contact with other globules, forming clusters of considerable size that rise much faster than individual globules. However, they do not behave strictly in accordance with Stokes' Law because they have an irregular shape and contain some milk serum.

#### Factors affecting creaming

Cream-layer volume is greatest in milk that has a high fat content and relatively large fat globules, because such milk contains more large clusters. However, temperature and agitation affect creaming, irrespective of the fat content of the milk. Heating to above 60°C reduces creaming; milk that is heated to above 100°C retains very little creaming ability.

Excessive agitation disrupts normal cluster formation, but creaming in cold milk may be increased by mild agitation since such treatment favours larger, loosely packed clusters.

#### Batch separation by gravity

Cream can be separated from milk by allowing the milk to stand in a setting pan in a cool place. This can be done in either of two ways.

**Shallow pan:** Milk, preferably fresh from the cow, is poured into a shallow pan 40 to 60 cm in diameter and about 10 cm deep. The pan should be in a cool place. After 36 hours practically all of the fat capable of rising by this method will have come to the surface, and the cream is skimmed off with a spoon or ladle (Figure 12). The skim milk usually contains about 0.5 to 0.6% butterfat.

**Deep-setting:** Milk, preferably fresh from the cow, is poured into a deep can of small diameter. The can is placed in cold water and kept as cool as possible. After 24 hours the separation is usually as complete as it is possible to secure by this method. The skim milk is removed through a tap at the bottom of the can (Figure 12). Under optimum conditions, the fat content of the skim milk averages about 0.2 or 0.3%.

The pans should be rinsed with water immediately after use, scrubbed with hot water and scalded with boiling water (see section on cleaning).





## 8.1.2 Centrifugal separation

Gravity separation is slow and inefficient. Centrifugal separation is quicker and more efficient leaving less than 0.1% fat in the separated milk compared with 0.5–0.6% after gravity separation.

The centrifugal separator was invented in 1897. By the turn of the century it had altered the dairy industry by making centralised dairy processing possible for the first time. It also allowed removal of cream and recovery of the skim milk in a fresh state.

The separation of cream from milk in the centrifugal separator is based on the fact that when liquids of different specific gravities revolve around the same centre at the same distance with the same angular velocity, a greater centrifugal force is exerted on the heavier liquid than on the lighter one. Milk can be regarded as two liquids — the serum and the fat — of different specific gravities.

Milk enters the rapidly revolving bowl at the top, middle or bottom (Figure 13). When the bowl is revolving rapidly the force of gravity is overcome by the centrifugal force which is 5000 to 10 000 times greater than gravitational force. Every particle in the rotating vessel is subjected to a force which is determined by the distance of the particle from the axis of rotation and its angular velocity.

Figure 13. Cutaway diagrams of (a) hand-operated milk separator and (b) the bowl showing the paths of milk and cream fractions.



If we substitute centrifugal acceleration  $(r_1w^2)$  for acceleration due to gravity (g), we obtain:

$$V = \frac{r^2(d_1 - d_2) r_1 w^2}{9n}$$

where:

 $R_1$  = radial distance of particle from centre of rotation

 $W^2 = a$  measurement of angular velocity.

Thus, sedimentation rate is affected by  $r_1w^2$ . In gravity separation, the acceleration due to gravity is constant. In centrifugal separation, the centrifugal force acting on the particle can be altered by altering the speed of rotation of the separator bowl.

In separation, milk is introduced into separation channels at the outer edge of the disc stack and flows inwards. On the way through the channels, solid impurities are separated from the milk and thrown back along the undersides of the discs to the periphery of the separator bowl, where they collect in the sediment

space. As the milk passes along the full radial width of the discs, the time passage allows even small particles to be separated. The cream, i.e. fat globules, is less dense than the skim milk and therefore settles inwards in the channels towards the axis of rotation and passes to an axial outlet. The skim milk moves outwards to the space outside the disc stack and then through a channel between the top of the disc stack and the conical hood of the separator bowl (Figure 13).

Efficiency of separation is influenced mainly by four factors: the speed of the bowl, residence time in the bowl, the density differential between the fat and liquid phase and the size of the fat globules.

#### Speed of the separator

Reducing the speed of the separator to 12 rpm less than the recommended speed results in high fat losses with up to 12% of the fat present remaining in the skim milk.

#### Residence time in the separator

Overloading the separator reduces the time that the milk spends in it and consequently reduces skimming efficiency. However, operating the separator below capacity gives no special advantage — it does not increase the skimming efficiency appreciably but increases the time needed to separate a given quantity of milk.

#### **Effect of temperature**

Freshly drawn, uncooled milk is ideal for exhaustive skimming. Such milk is relatively fluid and the fat is still in the form of liquid butterfat. If the temperature of the milk falls below 22°C skimming efficiency is seriously reduced. Milk must therefore be heated to liquify the fat. Heating milk to 50°C gives the optimum skimming efficiency.

#### Effect of the position of the cream screw

The cream screw regulates the ratio of skim milk to cream. Most separators permit a rather wide range of fat content of cream (18–50%) without adversely affecting skimming efficiency. However, production of cream containing less than 18% or more than 50% fat results in less efficient separation.

#### **Other factors**

Other factors that affect the skimming efficiency are the quality of the milk and maintenance of the separator. Milk in poor physical condition or which is curdy will not separate completely and a separator in poor mechanical condition will not separate milk efficiently.

When separation is complete the separator must be dismantled and cleaned thoroughly.

## 8.1.3 Hand separator

Following the course of milk through a separator bowl (Figure 13a) helps understand how centrifugal separation works. As milk flows into a rapidly revolving bowl it is acted upon by both gravity and the centrifugal force generated by rotation. The centrifugal force is 5000 to 10 000 times that of gravity, and the effect of gravity thus becomes negligible. Therefore, milk entering the bowl is thrown to the outer wall of the bowl rather than falling to the bottom.

Milk serum has a higher specific gravity than fat and is thrown to the outer part of the bowl while the cream is forced towards the centre of the bowl.

#### Assembling the bowl

- 1. Fit the milk distributor to the central feed shaft.
- 2. Fit the discs on top of each other on the central shaft.
- 3. Fit the cream screw disc.
- 4. Fit the rubber ring to the base of the bowl.

- 5. Put on the bowl shell, ensuring that it fits to the inside of the base.
- 6. Screw the bowl nut on top.

The rest of the separator is essentially a set of gears arranged to permit the spindle, on which the bowl is carried, to be turned at high speed. The gears are normally enclosed in an oil-filled case. The bowl is usually supported from the bottom and has two bearings; one to support its weight and the second to hold it upright. The upper bearing is usually fitted inside a steel spring so that it can keep the bowl upright even if the frame of the machine is not exactly level.

The assembled bowl is lowered into the receptacle, making sure that the head of the spindle fits correctly into the hollow of the central feed shaft.

#### Operation

- 1. When the bowl is set, fit the skim milk spout and the cream spout.
- 2. Fit the regulating chamber on top of the bowl.
- 3. Put the float in the regulating chamber.
- 4. Put the supply can in position, making sure that the tap is directly above and at the centre of the float.
- 5. Pour warm (body temperature) water into the supply can.
- 6. Turn the crank handle, increasing speed slowly until the operating speed is reached. This will be indicated on the handle or in the manufacturer's manual of operation. The bell on the crank handle will stop ringing when the correct speed is reached.
- 7. Open the tap and allow warm water to flow into the bowl. This rinses and heats the bowl, allows a smooth flow of milk and increases separation efficiency.
- 8. Pour warm milk (37–40°C) into the supply can. Repeat steps 6 and 7 above and collect the skim milk and cream separately.
- 9. When all the milk is used up and the flow of cream stops, pour about 3 litres of the separated milk into the supply can to recover residual cream trapped between the discs.
- 10. Continue turning the crank handle and flush the separator with warm water.

#### Cleaning the separator

Many of the impurities in the milk collect as slime on the wall of the separator bowl. This slime contains remnants of milk, skim milk and cream, all of which will decompose and ferment unless removed promptly.

If not thoroughly washed the separator bowl becomes a source of microbial contamination. Skimming efficiency is also reduced when the separator bowl and discs are dirty, and milk deposits on the separator can cause corrosion.

#### Washing the separator

After flushing the separator with warm skim milk, the bowl should be flushed with clean water until the discharge from the skim milk spout is clean. This removes any residual milk solids and makes subsequent cleaning easier. The bowl should then be dismantled and all parts (bowl, bowl cover, discharge spouts, float supply tank and buckets) washed with a brush, hot water and detergent. Rinse with scalding water and allow the parts to drain in a clean place protected from dust and flies. This process should be followed after each separation.

#### Cream screw adjustment

The cream screw should be adjusted so that the fat content of the cream is about 33%. Producing excessively thin cream reduces the amount of separated milk available for other uses and increases the volume of cream to be handled. Low-fat cream is also more difficult to churn efficiently.

Cream containing more than 45% fat clogs the separator and causes excessive loss of fat in skim milk. Cream of abnormally high fat content also gives butter a greasy body due to lack of milk SNF. When adjusting the cream screw it is important to remember that it is very sensitive; a quarter turn of the screw is sufficient to change the percentage fat in the cream appreciably.

The fat content of whole milk influences that of cream and this must be considered when adjusting the cream screw. For example, if the cream screw is set to separate milk at a ratio of 85 parts of separated milk to 15 parts of cream then, with all other conditions constant and assuming efficient separation, milk of 3% fat produces cream of 20% fat whereas milk of 4.5% fat produces cream of 30% fat.

The fat content of the cream can be calculated using the following equation:

$$Fc = \frac{Wm \times Fm}{Wc}$$

where :

Wm = weight of milk

Wc = weight of cream

Fm = fat content of milk

Fc = fat content of cream

In the first example, 
$$Fc = \frac{100 \times 3}{15} = 20$$

In the second example,  $Fc = \frac{100 \times 4.5}{15} = 30$ 

Therefore the setting of the cream screw depends on the fat content of the milk being separated. The milk should be mixed thoroughly before separation to ensure even distribution of cream in the milk.

## 8.1.4 Separator maintenance

- The gears must be well lubricated. Follow the directions of the manufacturer.
- The level of the lubricant must be kept constant; observe the oil level through the sight glass.
- The bowl must be perfectly balanced.
- The bowl should be cleaned thoroughly immediately after use to ensure proper functioning of the separator and for hygiene.

# 8.1.5 Calculations

Once milk passes through a separator it is recovered in two fractions, the high-fat cream fraction and the low-fat skim milk.

Assuming negligible loss of fat in the separator, the amount of fat entering the separator with the whole milk will be collected at the other side of the separator in either the cream or the skim milk. Therefore, if we separate 200 kg of milk containing 4.5% butterfat, what weight of cream containing 30% butterfat can we expect? Let Wm = weight of milk

Fm = fat content of the milk

Wc = weight of cream

Fc = fat content of the cream

Ws = weight of skim milk

Assuming that all of the fat present in the milk is recovered in the cream, then:

Wm x Fm = Wc x Fcand Wm - Wc = Wsand Wm - Ws = Wc Since  $Wm \ge Fm = Wc \ge Fc$ 

$$\frac{Wm \times Fm}{Fc} = Wc$$

Therefore  $Ws = Wm - \frac{Wm \times Fm}{Fc}$ 

In this case:

$$Ws = 200 - \frac{200 \times 4.5}{30}$$
  
= 200 - 30  
= 170 kg  
Since Wc = Wm - Ws

$$Wc = 200 - 170 = 30 \text{ kg}$$

Percentage yield of skim milk:

$$= \frac{W_{\rm S} \times 100}{Wm} = \frac{170 \times 100}{200} = 85\%$$

Percentage cream (%Wc)

$$=$$
 %Wm  $-$  %Ws

$$= 100 - 85 = 15\%$$

If in practice we obtain only 28 kg of cream containing 30% butterfat, then  $(2 \times 0.30)$  kg or 0.6 kg of butterfat has not been recovered in the cream. Since it is assumed that there are no significant losses of fat in the cream separator, the fat not recovered in the cream is lost in the skim milk.

Since 28 kg of cream was produced, and

$$Ws = Wm - Wc$$

then Ws = 200 - 28 = 172 kg

Thus there is 0.6 kg of fat in 172 kg of skim milk. The fat percentage of the skim milk is therefore:

$$\frac{0.6 \times 100}{172} = 0.35\%$$

Note: The skim milk contains 0.35% fat, which may be incorporated in cottage cheese. If the skim milk is consumed, no nutritional loss occurs, but a financial loss is incurred since the fat is more valuable if sold as butter than as cottage cheese.

The percentage of fat in milk and in cream influences Wc and Ws where the fat is recovered in the cream.

Fr = 3%  
Fr = 30%  
Wm = 100  
Then Wc = Wm x 
$$\frac{Fm}{Fc}$$
  
= 100 x  $\frac{3}{30}$  = 10 kg  
Ws = Wm - Wc  
= 100 - 10  
= 90 kg  
whereas if Fm = 4%  
Fc = 30  
Wm = 100

10 - 20/

Then Wc =  $100 \text{ x} \frac{4}{30} = 13.3 \text{ kg}$ Ws = 100 - 13.3= 86.6 kg

## 8.1.6 Standardisation of milk and cream

If fine adjustment of the fat content of cream is required or if the fat content of whole milk must be reduced to a given level, skim milk must be added. This process is known as standardisation.

The usual method of making standardisation calculations is the Pearson's Square technique. To make this calculation, draw a square and write the desired fat percentage in the standardised product at its centre and write the fat percentage of the materials to be mixed on the upper and lower left-hand corners. Subtract diagonally across the square the smaller from the larger figure and place the remainders on the diagonally opposite corners. The figures on the right-hand corners indicate the ratio in which the materials should be mixed to obtain the desired fat percentage.

The value on the top right-hand corner relates to the material on the top left-hand corner and the figure on the bottom right relates to the material at the bottom left corner.

#### **Example 1**



In this example, the fat content of whole milk is to be reduced to 3.0%, using skim milk produced from some of the whole milk. Using Pearson's Square, it can be seen that for every 2.9 litres of whole milk, 0.6 litres of skim milk must be added.

#### Example 2

How much skim milk containing 0.1% fat is needed to reduce the percentage fat in 200 kg of cream from 34% to 30%?



If 29.9 parts of cream require 4 parts of skim milk, 200 parts of cream require x parts of skim milk.

Weight of skim milk needed =  $x = \frac{200 \times 4}{29.9} = 26.75$  kg

#### Example 3

The fat content of 300 kg of whole milk must be reduced from 4.2% to 3% using skim milk containing 0.2% fat.



Every 4.0 kg of the mixture will contain 2.8 kg of whole milk and 1.2 kg of skim milk.

If 2.8 kg of whole milk requires 1.2 kg skim milk, 300 kg of whole milk requires

1.2 x  $\frac{300}{2.8}$  = 128.6 kg of skim milk

Thus, 128.6 kg of skim milk (0.2% fat) must be added to 300 kg of whole milk (4.2% fat) to give 428.6 kg of milk containing 3% fat.

#### **Example 4**

The fat content of milk must be reduced from 4.5 to 3% before sale as liquid milk but skim milk for standardisation is not available.

Assume that the fat content of 100 kg of milk containing 4.5% milk fat must be reduced to 3%. The amount of cream to be removed can be calculated as follows:

Let M = weight of milk to be standardised — in this example 100 kg. Therefore M = 100

Fm = fat content of the original milk = 4.5

C = weight of cream

Fc = fat content of the cream = 35

SM = weight of standardised milk

Fsm = fat content of the standardised milk = 3.0

Since the milk is separated into cream and standardised milk

SM + C = M

(1) or SM + C = 100

There are no fat losses therefore the weight of fat in the original milk will be equal to the weight of fat in the standardised milk and cream.

(Weight of fat in a product is the weight of product x % fat/100)

Therefore 
$$\frac{\text{SM} \times \text{Fsm}}{100} + \frac{\text{C} \times \text{Fc}}{100} = \frac{\text{M} \times \text{Fm}}{100}$$

or 
$$\frac{3 \times SM}{100} + \frac{35 \times C}{100} = \frac{100 \times 4.5}{100}$$
  
(2) or 0.03 SM + 0.35 C = 4.5

Equations (1) and (2) give two equations with two unknowns, so they can be solved as follows:

(1) SM + C = 100

(3) or 0.03 SM + 0.03 C = 3

Subtracting (3) from (2)

0.32 C = 1.5

C = 4.6875

= 4.7 corrected to one decimal place

The weight of cream is thus 4.7 kg.

Therefore, the weight of standardised milk is 95.3 kg.

Answer check

The original milk contained 4.5 kg of fat.

The cream contains  $\frac{4.7 \times 35}{100} = 1.645$  kg of fat.

Therefore 4.5 - 1.645 = 2.855 kg of fat in the standardised milk.

The fat percentage of the standardised milk is

$$\frac{2.855 \times 100}{95.3} = 3\%$$

Standardisation such as this can be used to increase income from milk production as follows:

Assume liquid milk price of EB 1.40/kg Assume butter price of EB 20/kg Income from 100 kg of milk = EB 140 Income from 95.3 kg of milk = EB 133.42 Fat removed = Wc x Fc =  $4.7 \times 0.35 = 1.645$  kg Expected butter yield = 1.9 kg Income from butter = EB 38 Total income = EB 171.42 Margin = EB 31.42/100 kg of milk

# 8.2 Buttermaking with fresh milk or cream

Butterfat can be recovered from milk or cream and converted to a number of products, the most common of which is butter. Butter is an emulsion of water in oil and has the following approximate composition:

Fat	80%
Moisture	16%
Salt	2%
Milk SNF	2%

In good butter the moisture is evenly dispersed throughout in tiny droplets. In most dairying countries legislation defines the composition of butter, and buttermakers conform to these standards insofar as possible. Butter can be made from either whole milk or cream, however, it is more efficient to make it from cream.

## 8.2.1 Buttermaking theory

To make butter, milk or cream is agitated vigorously at a temperature at which the milk fat is partly solid and partly liquid. Churning efficiency is measured in terms of the time required to produce butter granules and by the loss of fat in the buttermilk. Efficiency is influenced markedly by churning temperature and by the acidity of the milk or cream.

In churning, cream is agitated in a partly filled chamber. This incorporates a large amount of air into the cream as bubbles. The resultant whipped cream occupies a larger volume than the original cream. As agitation continues the whipped cream becomes coarser and eventually the fat forms semi-solid butter granules that rapidly increase in size and separate sharply from the liquid buttermilk. The remainder of the buttermaking process consists of removing the buttermilk, kneading the butter granules into a homogeneous mass and adjusting the water and salt contents to the levels desired.

## 8.2.2 Theory of the mechanism of churning

In considering the mechanism of churning the following factors must be taken into account:

- the function of air
- the release of the stabilising membrane surrounding the fat globules into the buttermilk
- the differences in structure between butter and cream
- the temperature dependence of the process.

Air is thought to be necessary for the process, but some workers have demonstrated that milk or cream can be churned in the absence of air, although it takes longer.

About one half of the stabilising material surrounding the fat globule is liberated into the buttermilk during churning. It is thought that during churning the fat globule membrane substance spreads out over the surface of the air bubbles, partly denuding the globules of their protective layer, and that a liquid portion of the fat exudes from the globule and partly or entirely covers the globule, rendering it hydrophobic. In this condition the globules tend to stick to the air bubbles.

Free fat destabilises the foam, causing it to collapse. The partly destabilised globules clinging to the air bubbles thus collect in clusters cemented together by free fat. These clusters appear as butter grains.

Cream prepared by gravitational or mechanical separation can be used to make butter. Good butter can be made in any type of churn provided it is clean and in good repair.

## 8.2.3 Churn preparation

The churn is prepared by rinsing with cold water, scrubbing with salt and rinsing again with cold water. Alternatively, it can be scalded with water at 80°C. After the butter has been removed, the churn should be washed well with warm water, scalded with boiling water and left to air. When not in use wooden churns should be soaked occasionally with water. A new churn should first be washed with tepid water, scrubbed with salt and then washed with hot water until the water comes away clear. A hot solution of salt should then be allowed to stand in the churn for about ten minutes. After rinsing again with hot water the churn should be left to air for at least one day before being used.

## 8.2.4 Churning temperature

The temperature of the cream during churning is of great importance. If too cool, butter formation is delayed and the grain is small and difficult to handle. If the temperature is too high, the butter yield will be low because a large proportion of the fat will remain in the buttermilk, and the butter will be spongy and of poor quality. Cream should be churned at 10-12°C in the hot season and at 14-17°C in the cold season. The temperature may be raised by standing the vessel containing the cream in hot water, and lowered by standing the vessel in cold spring water for a few hours before the cream is churned. The churning temperature may also be adjusted by the water used to dilute the cream. In the hot season, the coldest water available should be used, preferably water that has been stored in a refrigerator. The amount of cream to be churned should not exceed one half the volumetric capacity of the churn. An airtight churn should be ventilated frequently during the first 10 minutes of churning to release gases driven out of solution by the agitation. If butter is slow in forming, adding a little water which is warmer than the churning temperature, but never over 25°C, usually causes it to form more quickly. When the butter appears like wet maize meal, water (1 litre per 4 litres of cream) at 2°C below the churning temperature should be added. It may be necessary to add water a second time to maintain butter grains of the required size. Churning should cease when the butter grains are the size of small wheat grains.

## 8.2.5 Washing the butter

When the desired grain size is obtained, the buttermilk is drained off and the butter washed several times in the churn. Each washing is done by adding only as much water as is needed to float the butter and then turning the churn a few times. The water is then drained off. As a general rule two washings are enough but in very hot weather three may be necessary before the water comes away clear. In the hot season the coldest water available should be used for washing, and in the cold season water about 2 to 3°C colder than the churning temperature should be used.

# 8.2.6 Salting, working and packing the butter

Equipment for working may consist of a butter worker or a tub or keeler. Good-quality spatulas are important, and a sieve and scoop facilitate the removal of butter from the churn. This equipment must be clean. The butter is spread on the worker which has been previously soaked with water of the same temperature as the washing water. If salted butter is required, it should be salted before working at a rate of 16 g salt/kg or according to taste. Salt is added to butter most commonly using the dry-salting method in which dry salt is sprinkled evenly over the butter and worked in. The salt used should be dry and evenly ground and of the best quality available.

The butter is then either rolled out 8 to 10 times or ridged with the spatulas to remove excess moisture. Adding salt to butter disturbs the equilibrium of the emulsion (the butter). This in turn changes the character of the body and alters its colour. Unless the butter is subjected to sufficient working to regain the original equilibrium of the emulsion, it will tend to have a coarse, leaky body and uneven colour. The butter should be worked until it seems dry and solid, but it must not be worked too much or it will become greasy and streaky.

Butter must be adequately worked if it is to be stored for a long time. First, working distributes the salt uniformly in the moisture and this helps inhibit microbial growth. Secondly, it distributes the salt solution into many tiny droplets rather than fewer large ones. For a given level of microbial contamination, the microbes will be more isolated in small droplets and will have less of the butter's nutrients available to them for growth.

Surplus good-quality butter can be stored, but should contain more salt than usual—at least 30 g/kg —and a low moisture content (14–15%). The butter must be packed in clean containers, such as seasoned boxes or glazed crocks, and stored in a cold room or in a cold, airy place. If a box is used, it should be lined with good-quality polythene. The container should be filled to capacity from one churning. The more firmly butter is packed, the better; it may be covered with a layer of salt, but this is not essential. The container should be securely covered with a lid or a sheet of strong paper and stored in a cool, dark place.

# 8.2.7 Washing the churn and buttermaking equipment after use

The churn and buttermaking equipment should be washed as soon as possible, preferably while the wood is still damp.

Wash the inside of the churn thoroughly with hot water. Invert the churn with the lid on to clean the ventilator; this should be pressed a few times with the back of a scrubbing brush to allow water to pass through. The ventilator should be dismantled occasionally for complete cleansing.

Remove the rubber band from the lid and scrub the groove. Scald the inside of the churn with boiling water, invert and leave to air. Dry the outside and treat the steel parts with vaseline to prevent rusting. The rubber band should not be placed in boiling water; dipping in warm water is sufficient.

Place the sieve, scoop and spades on the butter worker or keeler and clean in the same way as the churn.

## 8.2.8 Overrun and produce in buttermaking

Two criteria that are used to check the efficiency of converting milk or cream into butter are "overrun" and "produce". Produce or butter ratio is the ratio of milk used to butter obtained from it. Overrun, which is usually calculated as per cent overrun, is the excess of butter made over butterfat used per 100 kg butter or the percentage increase of butter over butterfat.

#### Overrun

An enterprise engaged in buttermaking must be able to measure the efficiency of the process, i.e. by measuring the yield of butter from the butterfat purchased.

First, the theoretical yield of butter has to be estimated. Butter contains an average of 80% butterfat. Thus, for every 80 kg of butterfat purchased 100 kg of butter should be produced, or for every 100 kg of butterfat purchased 125 kg of butter should be produced.

The difference between the number of kilograms of butterfat churned and the number of kilograms of butter made is known as the overrun. This difference is due to the fact that butter contains non-fatty constituents such as moisture, salt, curd and small amounts of lactic acid and ash in addition to butterfat.

The overrun is financially important to the milk processor and constitutes the margin between the purchase price of butterfat and the sale price of butter. The dairy unit depends largely on overrun to cover manufacturing costs and to defray expenses incurred in the purchase of milk.

The maximum legitimate overrun is 25%. In commercial operation, however, it is not possible to establish the degree of accuracy that is assumed in the calculation of theoretical overrun. The actual overrun shows the difference between the amount of butter churned out and the amount of butterfat bought.

Overrun is affected by:

- accuracy of weighing milk received
- accuracy of sampling and testing milk for fat
- losses during separation
- efficiency of churning
- percentage of fat in the butter
- amount of salt and water in the butter
- amount of product loss throughout the process.

#### Notes:

1. The need for care when sampling milk for butterfat testing is referred to in Chapter 10. For example, if careless sampling and testing results in a reading of 3.6% butterfat against an actual content of 3.2% butterfat, what will be the effect on the overrun from 100 kg of milk?

Fat paid for =  $100 \ge 0.036 = 3.6 \ge 0.036 \le 3.6 \le 0.036 \le 3.6 \le 0.036 \le 3.6 \le 0.036 \le 3.6 \le 0.036 \le 0$ 

Butterfat paid for = 3.6 kg

Overrun  $=\frac{4}{3.6} = 1.11$ 

Thus, carelessness at the testing stage can result in serious manufacturing losses. Losses at any stage in the process should be avoided. If overrun is low, each step of the process should be checked carefully to trace the loss.

A more comprehensive calculation of overrun is given in Appendix 1.

 The non-fatty constituents of butter are moisture, salt and curd. In most of the principal butter-producing countries the percentage of moisture in butter is limited to 16%. Salt content varies largely according to market requirements and can be as high as 3%. Curd content is fairly uniform at 0.5–0.75%.

Any practice that increases the percentage of non-fatty constituents in butter automatically lowers the percentage of fat and increases the overrun. It is because of this that most countries legislate for a minimum of 80% butterfat in butter.

Butter composition also affects overrun. If the moisture content of butter is 14% instead of 16%, 2% more of the total weight must be provided by butterfat. This reduces the theoretical overrun from 25% to 21.95%

#### Produce

Another method of estimating the efficiency of a process is to measure the number of litres of milk required to make one kilogram of butter.

For example, how many litres of milk containing 4% butterfat are required to make 1 kg of butter?

In 1 kg of butter there is 0.80 kg of butterfat.

In milk there are 4 kg fat/100 kg or per  $\frac{100}{1.032}$  litres.

Therefore :

1 kg fat in  $\frac{100}{1.032 \times 4} = 24.22$  litres

or 0.8 kg fat in 19.38 litres.

Therefore 19.38 litres of milk containing 4% fat will be required to make 1 kg of butter. Thus the efficiency of operation can also be checked by calculating output.

The fat content of the whole milk, skim milk and buttermilk should be checked daily. The moisture content of the butter should be checked for each batch. The accuracy of weighing scales and other measuring devices should also be checked regularly.

## 8.2.9 Butter quality

The first step the producer can take to ensure a high-quality product is to make sure the manufacturing process is hygienic. This results in fewer spoilage organisms in the butter. Another step is to take care in the handling and storage of the butter. Using permitted preservatives is by far the most effective means of maintaining butter quality when used in conjunction with the above precautions. Salt is an excellent preservative, and salting butter to 3% extends its storage life; salted butter can be stored for up to four months without significant deterioration. An added advantage of adding salt is that it also increases overrun. A salt concentration in excess of 3% gives little advantage and can adversely affect the flavour of the butter.

Butter quality can be discussed under two main headings:

- Compositional quality
- Organoleptic quality.

The compositional quality of butter can be further divided into two subsections, namely chemical and bacteriological.

#### **Compositional quality**

The chemical composition of butter is determined at the processing stage when the salt, moisture, curd and fat contents of the product are regulated. Once these parameters have been set there is little one can do to change them. The microbiological quality of butter is also determined during the production and processing stages.

Chemical composition affects butter yield, while butter of poor microbiological quality will deteriorate rapidly and become unacceptable to consumers. Cleanliness at all stages of production is, therefore, essential, to preserve the quality and wholesomeness of butter.

#### **Organoleptic quality**

The organoleptic quality of butter can be described as the customer's reaction to its colour, texture and flavour. It has been said that the consumer tastes with his or her eyes, and it is true that a person's initial impression of a food will often determine whether or not he or she will buy it. It is important, therefore, to produce butter that has an even colour, clean flavour and close texture. It is also important that it is free from defects such as loose moisture. It should be packed attractively, both to attract customer attention and to retain its quality.

Butter produced carelessly and without salt may have a very short shelf-life. Preservation of butter quality can assist the smallholder in two ways. The less perishable the product the longer the smallholder can retain it to obtain a good price and the surplus made during the production season can be stored for consumption during the season in which butter is not being produced.

## 8.3 Buttermaking with sour whole milk

Smallholder milk processing is based on sour milk. This is due to a number of reasons including high ambient temperatures, small daily quantities of milk, consumer preference and increased keeping quality of sour milk.

Products made from sour milk include fermented milks, concentrated fermented milks, butter, ghee, cottage cheese and whey. Other products are made by mixing fermented milk with boiled cereals.

The equipment required for processing sour milk is simple and available locally. Milk vessels can be made from clay, gourds and wood, and can be woven from fibre, such as the *gorfu* container used by the Borana pastoralists in Ethiopia. The products and by-products of buttermaking from sour whole milk are shown in Figure 14.

## 8.3.1 Buttermaking

This is a very important process in many parts of Africa and countries with a developing dairy industry. Smallholders produce one to four litres of milk per day for processing. Under normal storage conditions the milk becomes sour in four to five hours. Souring milk has a number of advantages. It retards the growth of undesirable micro-organisms, such as pathogens and putrefactive bacteria and makes the milk easier to churn.

Milk for churning is accumulated over several days by adding fresh milk to the milk already accumulated. The churn may hold up to 20 litres and the amount of milk churned ranges from 4 to 10 litres. Butter is made by agitating the milk until butter grains form. The churn is then rotated slowly until the fat coalesces into a continuous mass. The butter thus formed is taken from the churn and kneaded in cold water.

The milk is usually agitated by placing the churn on a mat on the floor and rolling it to and fro. It can also be agitated by shaking the churn on the lap or hung from a tripod.

The International Livestock Centre for Africa (ILCA) has developed a wooden agitator that fits inside a clay pot which is the traditional type of churn in many parts of Africa (Appendix XII). Using this internal agitator cuts churning time in half and increases recovery of butterfat as butter.

Figure 14. Products and by-products of buttermaking from sour whole milk.



A number of factors influence churning time and recovery of butterfat as butter:

- milk acidity
- churning temperature.
- degree of agitation
- extent of filling the churn.

#### Effect of acidity

Fresh milk is difficult to churn — churning time is long and recovery of butterfat is poor — however, milk containing at least 0.6% lactic acid is easier to churn. Acidity higher than 0.6% does not significantly influence churning time or fat recovery.

## Effect of temperature<sup>1</sup>

Sour milk is normally churned at between 15 and 26°C, depending on environmental temperature. At low temperatures churning time is long; butter-grain formation can take five hours or longer. As churning temperature increases churning time decreases. ILCA trials have shown that when churning sour whole milk using the traditional method, fat recovery values of 67% and 44% were obtained with churning temperatures of 18°C and 25°C, respectively. Controlling the temperature is therefore critical. The optimum churning temperature is between 15 and 17°C.

<sup>1.</sup> It is difficult to isolate the effects of temperature and acidity on churning efficiency because as the milk ripens it also cools and the fat crystallises. Direct acidification of fresh milk increases butter yield, but allowing milk to develop acidity during a ripening period of two to three days allows considerable fat crystallisation.

#### **Degree of agitation**

Increasing agitation reduces churning time. Fitting an agitator to a traditional churn reduces churning time and increases butter yield. The percentage of fat recovered as butter is increased, with as little as 0.2% fat remaining in the buttermilk. The advantage of using the ILCA internal agitator was demonstrated when churning sour whole milk at 18°C. Using the traditional clay pot a fat recovery of 67% was obtained compared to a 76% fat recovery when using the clay pot fitted with the internal wooden agitator.

#### Extent of filling the churn

Churns should be filled to between a third and half their volumetric capacity. Filling to more than half the volumetric capacity increases churning time considerably but does not reduce fat recovery.

Thus, when churning whole milk, the following conditions should be adhered to:

- milk acidity should be greater than 0.6%
- the temperature should be adjusted to about 18°C
- internal agitation should be used to reduce churning time and increase fat recovery
- the churn should not be filled to more than half its volumetric capacity.

Once the fat has been recovered by churning the buttermilk contains casein, whey proteins, milk salts, lactic acid, lactose, the unrecovered fat and some fat globule membrane constituents. Buttermilk is suitable, and is often used, for direct consumption. It is also used to inoculate fresh milk to encourage acid development and for cheesemaking.

# 8.4 Ghee, butter oil and dry butterfat

These products are almost entirely butterfat and contain practically no water or milk solids-not-fat (SNF). Ghee is made in eastern tropical countries, usually from buffalo milk. An identical product called *samn* is made in Sudan. Much of the typical flavour comes from the burned milk SNF remaining in the product. Butter oil or anhydrous milk fat is a refined product made by centrifuging melted butter or by separating milk fat from high-fat cream.

Ghee is a more convenient product than butter in the tropics because it keeps better under warm conditions. It has low moisture and milk SNF contents, which inhibits bacterial growth.

Milk or cream is churned as described in the sections dealing with churning of sour whole milk or cream. When enough butter has been accumulated it is placed in an iron pan and the water evaporated at a constant rate of boiling. Overheating must be avoided as it burns the curd and impairs the flavour. Eventually a scum forms on the surface and can be removed using a perforated ladle. When all the moisture has evaporated the casein begins to char, indicating that the process is complete. The ghee can then be poured into an earthenware jar for storage.

A considerable amount of moisture and milk SNF can be removed before boiling by melting the butter in hot water (80°C) and separating the fat layer. The fat can be separated either by gravity or using a hand separator. The fat phase yields a product containing 1.5% moisture and little fat is lost in the aqueous phase.

Alternatively, the mixture of butter and hot water can be allowed to settle in a vessel similar to that used in the deep-setting method for separating whole milk. Once the fat has solidified the aqueous phase is drained. The fat is then removed and heated to evaporate residual moisture. Products made using these methods have excellent keeping qualities with a shelf-life of about six months at ambient temperature.

# 8.5 Cheesemaking using fresh milk

Cheese is a concentrate of the milk constituents, mainly fat, casein and insoluble salts, together with water in which small amounts of soluble salts, lactose and albumin are found. To retain these constituents in concentrated form, milk is coagulated by direct acidification, by lactic acid produced by bacteria, by adding rennet or a combination of acidification and addition of rennet.

## 8.5.1 Rennet coagulation theory

Rennet, a proteolytic enzyme extracted from the abomasum of suckling calves, was traditionally used for coagulating milk. Originally the abomasum was itself immersed in milk. The extraction of rennet which could be stored as a liquid was the first step towards refining this procedure. This was followed by purification and concentration of the enzyme. The purified enzyme was originally called rennin and is now called chymosin.

On weaning the chymosin of the suckling calf is replaced by bovine pepsin. With the decrease in the practice of slaughtering calves chymosin became scarce resulting in a search for chymosin substitutes. Rennet is a general term currently used to describe a variety of enzymes of animal, plant or microbial origin used to coagulate milk in cheesemaking.

Rennet transforms liquid milk into a gel. While the process is not fully understood, rennet coagulation is thought to take place in two distinct phases, the first of which is regarded as being enzymatic, the second non-enzymatic. The first, or primary phase, can be illustrated as:

Since k-casein stabilises the other caseins and its hydrolysis leads to the coagulation of the casein fraction, the primary phase can also be expressed as:

water k-casein — para k-casein + glycomacropeptide rennet (insoluble) (soluble)

The effect of milk coagulants on the other caseins is thought to be negligible at this stage.

The second, or secondary, phase is the non-enzymatic precipitation of para casein by calcium ions. Para casein, in association with the calcium ions, is thought to produce a lattice structure throughout the milk. This traps the fat and whey is gradually exuded. The coagulum then contracts, a process known as syneresis. This is accelerated by increasing the temperature and reducing pH to as low as pH 4.6.

Rennet also has a tertiary action on milk proteins. This occurs during cheese ripening when rennet hydrolyses milk proteins. If the desired hydrolysis is not obtained, the cheese becomes bitter. While a wide variety of proteolytic enzymes coagulate milk, the tertiary action of many of these on milk proteins causes undesirable flavours in cheese, which limits the range of coagulants that can be used.

## 8.5.2 Cheese varieties

Many cheese varieties are manufactured around the world but they are all broadly classified by hardness, i.e. very hard, hard, semi-soft and soft, according to their moisture content.

Cheese is usually made from cow milk, although several varieties are made from the milk of goats, sheep or horses.

#### White cheese

*Queso blanco* (white cheese) is of Latin American origin. It is usually made from milk containing about 3% fat. Starter or rennet is not used and curd precipitation is brought about by an organic acid usually in the form of lemon juice. *Queso blanco* is a pressed cheese (it contains less moisture than unpressed cheese) and therefore has a longer shelf-life than soft curd cheese. The milk is heated to a high temperature (over 80°C) and this also contributes to the increased shelf-life of the cheese. *Queso blanco* is an ideal cheese for manufacture by smallholders as all the materials required may be obtained or made locally. The expected yield is one kilogram of cheese from eight litres of milk.

#### Method

- 1. Fresh whole milk is used. The fat content of the milk should be reduced to about three per cent. The fat content in milk from local cows is usually between five and six per cent. To reduce the fat content, allow the milk selected for cheesemaking to stand for about one hour then skim off the top layer (high fat milk or cream). The cream can be used for buttermaking.<sup>2</sup>
- 2. Heat the milk to about 85°C to destroy most of the bacteria present and also to increase yield through precipitation of the whey proteins .
- 3. Dilute lemon juice with an equal quantity of clean, fresh water so that the lemon juice can be distributed uniformly. Add about 30 ml of lemon juice per litre of milk. Stir the milk while carefully adding the lemon juice (Figure 15). The curd precipitates almost immediately.

Figure 15. Adding lemon juice and stirring the milk.



- 4. Continue stirring for about three minutes after adding the lemon juice (Figure 16).
- 5. Allow the curd to settle for 15 minutes. Separate the curds from the whey by draining through a sieve or a muslin (cheese) cloth (Figure 17).
- 6. While draining the whey, stir the curd to prevent excess matting.
- 7. Add salt to the curd at a rate of about 4 g for every 100 g of curd and mix properly. The quantity of salt may be varied to cater for consumer taste preferences.
- 8. Transfer the curd to a mould (container) lined with cheese cloth. The mould may be cylindrical or squareshaped and may be made from metal, plastic or wood (Figure 18).
- 9. Cover the curd by folding over the cheese cloth. Fit a wooden follower neatly inside the mould to enable the curd to be pressed.

<sup>2.</sup> The length of time the milk is allowed to stand before skimming can be varied depending on the final cheese quality and consumer acceptability.

Figure 16. Stirring the curds and whey.



Figure 17. Separating the curds from the whey using a muslin cloth.



Figure 18. Adding curd to a muslin-lined mould.



- 10. Press the curd overnight by placing metal weights on top of the wooden follower (Figure 19).<sup>3</sup>
- 11. Store the cheese as it is or cut it into suitably sized pieces for sale.
- 12. Coat the cheese with a thin film of butter to enhance the appearance.

#### Halloumi

*Halloumi* is a firm pickled cheese with its origins in Cyprus where it is made from sheep or goat milk or a mixture of both. It can also be made from cow milk. Starter is not used. The cheese may be eaten fresh or after storage in a cool store. If it is stored at below  $12^{\circ}$ C it will keep for several months. After salting the cheese pieces may also be stored in plastic bags without brining; if stored at about  $10^{\circ}$ C the cheese has a shelf-life of two to three months. About one kilogram of cheese will be obtained from nine litres of milk.

#### Method

- 1. If necessary pasteurise the milk by heating to 73°C for about 20 seconds and cool immediately to 32°C.
- 2. Add rennet extract (about 3 ml per 10 litres of milk). This should give a firm curd in 40-45 minutes.
- 3. Cut the curd into 3–4 cm cubes using horizontal and vertical curd cutting knives.
- 4. Stir the curds and whey mixture gently and heat to 38–42℃. Stir for 20 minutes after this temperature is reached.
- 5. Allow the curd to settle.

<sup>3.</sup> Different types of mechanical cheese presses are available. The weight to use can be determined through experience. Too much pressure will result in losses of fat in the expressed whey giving reduced yield and a poor textured cheese. If the whey expressed from the cheese during pressing is milky white then too much pressure is being applied. If too little pressure is used the curds do not mat properly and this will give a cheese with poor body and texture. The flavour may also be affected because of entrapped whey between the curd particles. If stored at a cool temperature (15°C) and protected from flies and rodents the cheese has a shelf-life of several months.

Figure 19. Pressing cheese.



- 6. Ladle the whey off the curd and scoop the curd into a mould lined with cheese cloth. Press for about four hours.
- 7. Heat the collected whey to 80-90°C.
- 8. Remove the cheese from the press and cut it into 10 cm x 2 cm pieces (Figure 20).
- 9. Place the curd pieces in the hot whey. At first the curd pieces sink but when properly textured they rise to the surface (Figure 21). Transfer the pieces to a draining table.
- 10. After about 20 minutes the curd pieces are cool. Sprinkle the curd with 3–5% salt and fold each piece over (Figure 22).
- 11. Place the cold curd pieces in containers. Fill the containers with 30% brine.

#### Gybna beyda

*Gybna beyda* is a hard white cheese made in Sudan. It is similar to *Domiati* which is made in Egypt. Starter is not used. The storage life of the cheese may be more than one year. About one kilogram of cheese will be obtained from seven litres of milk.

#### Method

- 1. Heat fresh milk to  $35^{\circ}$ C and add salt to give a 7–10% salt solution in the milk.
- 2. Add rennet or rennet extract to obtain a firm coagulum in four to six hours.
- 3. Transfer the coagulum to wooden moulds lined with muslin and allow the whey to drain overnight.
- 4. Cut the curd into 10 cm cubes. Put the cubes into tins or other suitable airtight containers.
- 5. Fill the tin or container with whey and seal.

Figure 20. Cutting the curd mass.



Figure 21. Floating cheese pieces.



Figure 22. Cheese pieces folded over after salting.



#### Wara, Woagachi

The names *Wara, Woagachi, Warankasi,* Nigerian white cheese and West African soft cheese refer to the same type of cheese. The manufacture of *Wara* cheese is widespread in Nigeria and a similar cheese called *Woagachi* is made in the northern provinces of the Benin Republic. While the manufacturing processes of *Wara* and *Woagachi* are essentially the same there are significant and interesting variations. *Woagachi* cheese is larger (600 g) than *Wara* (60 g) cheese. This is because of the size of the basket type mould which is used. In Benin one or two larger cheeses are made during a single process while about 10–20 pieces of *Wara* are made at any one time. *Woagachi* cheese is usually coloured in a hot solution of the leaves and stems of red sorghum while *Wara* cheese is sold uncoloured.

The preferred coagulating agent is the juice extract of *Calotropis procera* but the juice extract from papaya leaves and stems is sometimes used. *Wara* cheese is invariably sold on the day of manufacture and is brought to the market in a container of cool water. However, *Woagachi* may be stored for several days after it has been dipped in a salt solution for a few hours followed by immersion in the hot red sorghum solution for a few seconds. The manufacturing process, i.e. heating the milk, cooking and ladling of the curds and whey into baskets (moulds) is similar for both types of cheese. During heating a skin (fat and protein) forms on the top of the unstirred milk. Traditionally this skin is skimmed off and is either discarded or used for cooking purposes. This practice leads to some losses of valuable milk nutrients and reduces the cheese yield. In addition, heating the milk without stirring causes burn-on of milk solids on the base of the container andresults in some discoloured particles in the finished cheese. It is recommended therefore, that the milk is stirred gently and intermittenly during the heating process to avoid the formation of skin and the burn-on of milk solids.

Botanists will be aware of the many reputed uses of the juice extract of *C. procera*. Among its reported uses are medicinal, i.e. putting it on a cut or flesh wound or as an aphrodisiac and also as a poison to kill animals or human beings. That *C. procera* juice extract contains toxic substances may give cause for alarm but there is no evidence to suggest that consumers are adversely affected or are in any danger to their health following consumption of *Wara* or *Woagachi* cheese. It appears that toxins in the *C. procera* juice extract

are destroyed by the high temperature (95°C) to which the milk is heated. Both types of cheese are generally sold within a day or, in some cases, within hours of manufacture. The yield of cheese varies with its composition; the higher the moisture content the greater the yield. The moisture content of *Wara* and *Woagachi* is about 65%. *Wara* cheese is unsalted and uncoloured. About one kilogram of cheese will be obtained from about five litres of milk.

#### Method

- 1. Fresh morning milk is usually used. Transfer whole milk (about five litres) from the milking vessel to a metal pot.
- 2. Place the metal pot over a slow burning fire or a fire of smouldering wood and heat to a temperature of about 50°C. This usually takes about half an hour.
- 3. Stir the milk gently during the initial and subsequent heating and cooking.
- 4. Add the *C. procera* juice extract to the warmed milk.<sup>4</sup> To prepare the extracts, finely chop about eight medium-sized leaves of *C. procera* and add them to about 100 ml (about half a cup) of warm water. After about five minutes sieve this water/juice extract into 5–6 litres of already warmed milk.
- 5. Heat the milk slowly with intermittent stirring until it reaches boiling point.
- 6. Keep the milk at boiling point until it coagulates and there is visible separation of curds and whey.
- 7. Remove the pot from the fire.
- 8. Ladle or pour the curds and whey into baskets placed over a container for whey collection. The basket or mould facilitates whey drainage and also gives the cheese (*Wara* or *Woagachi*) its characteristic shape and size (Figures 23 and 24).
- 9. When the cheese is firm enough to retain its shape remove it from the basket and place it in a container of cool water (Figure 24).
- 10. Soak Woagachi cheese in brine (20% NaCl) for 12–15 hours then dip it for a few seconds in a hot solution of the stems and leaves of red sorghum.<sup>5</sup>

#### Cheddar

Cheddar cheese has its origins in Britain. Traditionally the cheese was made in different sizes from about 0.5 to 25 kg. The procedure for making Cheddar may be considered difficult and tedious by the inexperienced but the resultant mature cheese with its characteristic nutty flavour and close texture makes the task worthwhile. The Cheddar cheese recipe can be manipulated to give a cheese which may be consumed in four weeks or stored for up to two years. Therefore Cheddar offers the opportunity to preserve milk constituents in times of surplus milk production.

In order to obtain a cheese of good body and texture it is necessary to use milk with about 3.3% fat. If milk with excess fat content is used there will be high losses of fat in the whey and the cheese will have a weak, pasty body.

#### Method

- 1. Use milk containing about 3.3% fat. Warm it to 30°C.
- 2. Add starter (2%) to the warm milk.

<sup>4.</sup> The method of addition of the juice extract depends on the preference of the cheesemaker. While some cheesemakers prefer to swirl the crushed leaves and stems in the milk for a few minutes others prefer to place the crushed leaves and stems in a piece of muslin or similar type cloth and swirl the cloth and its contents in the milk for a few minutes. Obviously these methods of juice addition lead to variations in the actual quantities of juice being retained in the milk.

<sup>5.</sup> Because of the local demand for Wara and Woagachi the question of extending the shelf-life of the cheese does not arise. However, with anticipated increases in milk production and therefore, cheese production, it will be necessary to extend the shelf-life of the cheese to cater for increased storage and transport times. The increased shelf-life may be accomplished by the combined effects of incorporating about 2% salt in the cheese and by pressing the cheese to reduce its moisture content to about 50%.

Figure 23. Ladling curds and whey into a cheese mould.



Figure 24. Whey draining and, in the foreground, cheese pieces in cool water.



- 3. After about half an hour add rennet at a rate of 1 ml per 4 litres of milk. Before adding the rennet, dilute it five to six times with clean cold water.
- 4. When the curd is firm enough (Figure 25), i.e. in 40-50 min, cut it into 1.25 cm cubes (Figure 26).
- 5. Stir the curds and whey and heat gradually to 38-40°C in about 50 min.
- 6. Continue stirring until the curd pieces have firmed and an acidity of 0.20% lactic acid has been reached.
- 7. Drain off the whey; the curds mat together.
- 8. When a small quantity of milk (10 litres) is used the curd is left as one piece but where large quantities of milk are used the matted curd is cut into appropriate sized blocks (Figure 27).
- 9. Keep the cheese block or blocks warm (30°C) and turn frequently until the correct texture and acidity is reached (Figure 28). This process (cheddaring) may take 1.5–2 hours after the whey is removed.
- 10. Break up the cheese blocks into small pieces (milling) about 3.4 cm long.
- 11. Add salt to the curd pieces at a rate of 2–2.5%. Distribute the salt evenly and mix well with the cheese curd.
- 12. Pack the salted curd into moulds lined with cheese (muslin) cloth and press (Figures 29 and 30). Apply pressure gently at first and then increase to ensure that the curd pieces mat. If too much pressure is applied the expressed whey from the curd is milky white indicating high fat losses while too little pressure results in poor matting of the curd pieces and a cheese which will not retain its shape during storage.
- 13. Store the cheese at ambient temperature; lower temperatures (15°C) will slow down the rate of ripening. Storage temperatures can therefore be varied to give a rapid or slow maturing cheese.
- 14. The ripening or storage period of the cheese can vary from four weeks to two years depending on the manipulation, e.g. rate of acid production of the recipe and temperature of storage.

Figure 25. Checking the coagulum before cutting.



Figure 26. Cutting the coagulum with a vertical knife.



Figure 27. Cutting the cheese curd.



Figure 28. Covering the curd with cheese cloth to keep it warm during cheddaring.



Figure 29. Putting the cheese into a muslin-lined mould.


Figure 30. Cheese ready for pressing.



#### Feta

This is a brine-pickled cheese that can be made from cow, sheep or goat milk. *Feta* can be made without starter and can also be made from standardised milk. The procedure described here is for the manufacture of a *feta*-type cheese without starter or additives.

The high salt concentration retards bacterial activity. However, the brining container should be airtight to prevent the growth of moulds.

*Feta* cheese can be eaten after a few days or stored for up to two years in the brine, provided the container is airtight. The cheese develops a soft, crumbly texture during ripening.

Expected yield: 1 kg of cheese from 9 kg of milk (11%).

#### Method

- 1. Standardise the milk to 3% fat, heat to about 32°C and allow to ripen for one hour before adding rennet.
- 2. Add commercial rennet at the rate of 25 ml/100 litres of milk. Leave the milk until a firm clot has formed. This usually takes 40 to 50 minutes.
- 3. Cut the curd into 2 to 3 cm cubes to facilitate whey drainage. Allow 15 minutes for the whey to separate. Stir intermittently during this time.
- 4. Allow the curds to settle and decant the supernatant whey.
- 5. Transfer the curds and some whey to cheese moulds lined with muslin. Place the lid on the mould and invert at half-hourly intervals in the first few hours to facilitate whey drainage.
- 6. Allow the curd to settle overnight.
- 7. Cut the curd mass into blocks of suitable size and sprinkle them with salt.
- 8. Place the salted blocks in a 15% brine solution to give 6–8% salt in the cheese at equilibrium.

### 8.5.3 Cheese yield

In cheesemaking, the milk fat and casein are recovered with some moisture. The cheese yield can be expressed in kilograms of cheese obtained per 100 kg of milk processed. Cheese yield is influenced by milk composition, the moisture content of the final cheese and the degree of recovery of fat and protein in the curd during cheesemaking.

Milk low in total solids will give a low cheese yield, while milk high in total solids will give a high cheese yield. To predict the theoretical yield of cheese, the fat and casein content of the milk must be known. Because of difficulties encountered in estimating casein content, the following formula, derived from results of experiments on Cheddar cheese, is often used to estimate cheese yield:

(2.3 x fat%) + 1.4 = cheese yield (kg/100 kg milk)

Therefore, with milk containing 4% fat the expected yield would be:

(2.3 x 4) + 1.4 = 10.6 kg/100 kg milk

This formula gives an estimate of cheese yield and is applied most often to Cheddar cheese. It is useful as an immediate check on efficiency, but a universal yield factor for cheese varieties is unrealistic.

If the cheese yield is less than expected, the following checks should be made:

- weigh and record milk received
- sample and analyse milk received
- weigh, store and record cheese made
- sample and analyse whey.

The fat content of whey should be analysed for each batch of cheese made.

In estimating the profitability of cheesemaking enterprises, an average annual yield of 9.5%, i.e. 9.5 kg of cheese per 100 kg of milk, is used. Milk may be standardised to increase cheese yield, particularly with high-fat milk. Standardisation also gives a good return for skim milk, however, over-standardising (reducing the fat content to below 3%) results in coarse-textured cheese with poor flavour.

High moisture content increases cheese yield, but reduces keeping quality. Cheese loses moisture during storage if it is not properly wrapped, thus reducing yield. Waxing reduces moisture loss, as does storing cheese in brine.

### 8.6 Cheesemaking with sour skim milk

The case in and some of the unrecovered fat in skim milk and buttermilk can be heat-precipitated as cottage cheese, known in Ethiopia as *ayib*.

The defatted milk is heated to about 50°C until a distinct curd mass forms. It is then allowed to cool gradually and the curd is ladled out. Alternatively, the curd can be recovered by filtering the cooled mixture through a muslin cloth. This facilitates more complete recovery of the curd and also allows more effective moisture removal. Temperature of heating can be varied between 40 and 70°C without markedly affecting product composition and yield. Heat treatments between 70 and 90°C do not appear to affect yield but give the product a cooked flavour.

The whey contains about 0.75% protein, indicating near-complete recovery of casein. Whey may be consumed by humans or fed to animals.

The approximate composition of cottage cheese made at smallholder level is 76% water, 14% protein, 7% fat and 2% ash. It has a short shelf-life because of its high moisture content. The shelf-life can be increased by adding salt, reducing the moisture content of the cheese or by storing the product in an airtight container.

Skim milk can be heated in any suitably sized vessel that is able to withstand heat. Heating can be direct or indirect. A ladle or muslin cloth can be used for product recovery.

The yield depends on milk composition and on the moisture content of the product, but should be at least l kg of cottage cheese from 8 litres of milk (12.5%).

### 8.7 Milk fermentation

Raw milk produced under normal conditions develops acidity. It has long been recognised that highly acid milk does not putrefy. Therefore, allowing milk to develop acidity naturally preserves the other milk constituents.

Bacteria in milk are responsible for acid development. They produce acid by the anaerobic breakdown of milk carbohydrate—lactose—to lactic acid and other organic acids. The conversion of carbohydrate to organic acids or alcohols is called fermentation.

Pyruvic acid formation is an intermediate step common to most carbohydrate fermentations:

C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> ---->2 CH<sub>3</sub>.CO.COOH

However, fermentations are usually described by the end product such as lactic acid or ethyl alcohol and carbon dioxide.

A number of sugar fermentations are recognised in milk. They can be either homofermentative, with one end product, or heterofermentative, with more than one end product. The fermentations discussed are outlined in Figure 31.

- The lactic acid fermentation is the most important one in milk and is central to many processes.
- Propionic fermentation is a mixed-acid fermentation and is used in the manufacture of Swiss cheese varieties.

Figure 31. Outline of four important lactose fermentations.



- Alcohol fermentation can be used to prepare certain fermented milks and also to make ethyl alcohol from whey.
- The coliform gassy fermentation is an example of a spoilage fermentation. Large numbers of coliform bacteria in milk indicates poor hygiene. The coliform gassy fermentation disrupts lactic acid fermentation, and also causes spoilage in cheese.

The factors that affect microbial growth also affect milk fermentation. Fermentation rates generally parallel the microbial growth curve up to the stationary phase. The type of fermentation obtained depends on the numbers and types of bacteria in the milk, storage temperature and the presence or absence of inhibitory substances.

The desired fermentations can be obtained by temperature manipulation or by adding a selected culture of micro-organisms — starter — to pasteurised or sterilised milk. In smallholder milk processing, a small quantity of milk from previous batches is often used to provide "starter" for subsequent batches. Other sources include the container and additives such as cereal grains.

The fermentation is established once the organisms dominate the medium and continues until either the substrate is depleted or the end product accumulates. In milk, accumulation of end product usually arrests the fermentation. For example, accumulation of lactic acid reduces milk pH to below 4.5, which inhibits the growth of most micro-organisms, including lactic-acid producers. The fermentation then slows and finally stops.

Fermented milks are wholesome foods and many have medicinal properties attributed to them.

### 8.7.1 Fermented milks

The types of fermented milk discussed here are those made by controlled fermentation. This is achieved by establishing the desired micro-organisms in the milk and by maintaining the milk at a temperature favourable to the fermentative organism.

A variety of fermented milks are made, each differing markedly from the other. However, a number of steps are common to each manufacturing process, and these are outlined in Figure 32.

### Standardisation

Occasionally some fat is removed or skim milk is added to the fresh whole milk. In some instances, the removal of moisture during sterilisation increases the proportion of solids in the final product.

### Heating

Milk is heated to kill pathogens and spoilage organisms and to provide a cleaner medium in which the desired micro-organisms can be established. Heating also removes air from the milk, resulting in a more favourable environment for the fermentative organisms, and denatures the whey proteins, which increases the viscosity of the product.

After heating, the milk must be cooled before it is inoculated with starter, otherwise the starter organisms will also be killed.

### **Inoculation with starter**

Starter is the term used to describe the microbial culture that is used to produce the desired fermentation and to flavour the product. When preparing the starter, care must be taken to avoid contamination with other micro-organisms. Companies that supply starter cultures detail the precautions necessary. Care should also be taken to avoid contamination when inoculating the milk with starter.

### Incubation

After inoculation the milk is incubated at the optimum temperature for the growth of the starter organism. Incubation continues until the fermentation is complete, at which time the product is cooled. Additives, e.g. fruit or herbs may be added at this stage and the product packed.

The manufacturing procedures for some fermented milks are given in Table 10.





Table 10. Manufacturing procedures for yoghurt, acidophilus milk and kefir.

Product	Milk	Standardise	Sterilise	Starter	Incubation temperature (°C)	Incubation time (hours)
Yoghurt	Cow	Optional	85°C	S. thermophilus	42	4–6
			30 min	L. bulgaricus		
Acidophilus	Cow	Optional	120°C	L. acidophilus	38	18–24
milk			20 min			
Kefir	Cow	_	85°C	<i>Kefir</i> grains <sup>1</sup>	22	12
	Ewe		30 min			
	Goat					
	Mare					

1. Kefir grains are irregular granules in which bacteria and yeast grow. When they are introduced into the milk, the micro-organisms on the granules bring about the fermentation.

#### Preparation of the fermentation vessel

The fermentation vessel is washed, dried and then smoked byputting burning embers of *Olea africana*, wattle or acacia into the vessel and closing the lid. The vessel is then shaken vigorously and the lid opened to release the smoke. This procedure is repeated until the inside of the vessel is hot. Smoking flavours the product and is also thought to control the fermentation by retarding bacterial growth. While it is known that smoke contains compounds that retard bacterial growth, the precise effects of smoking on fermentation have not been investigated.

Once smoking is complete the vessel may be cleaned with a cloth to remove charcoal particles. However, in some areas the charcoal particles are retained to add colour to the product.

#### Milk treatment

In some processes the milk is boiled before fermentation. It is then cooled and the surface cream removed. In other processes the milk is not given any pre-fermentation treatment.

#### Fermentation

The milk is placed in the smoked vessel and allowed to ferment slowly in a cool place at a temperature of about 16–18°C. The fermentation is almost complete after two days, but may be continued for a further two days, by which time the flavour is fully developed. The milk must ferment at low temperature otherwise fermentation is too vigorous with resultant wheying off and gas production. The product has a storage stability of 15 to 20 days.

### 8.7.2 Concentrated fermented milk

Concentrated fermented milk is prepared by removing whey from fermented milk and adding fresh milk to the residual milk constituents. The fermentation vessel is prepared as for fermented milk and the milk is allowed to ferment in a cool place for up to seven days, during which milk may be added daily. After seven days a coagulum has formed and the clear whey is removed. Fresh milk is then added and, following further fermentation, whey is again removed.

In this way the casein and fat are gradually concentrated in a product of extended keeping quality. The degree of concentration depends on the amount of whey removed and of fresh milk added.

# 9. Cleaning, sanitising and sterilising dairy equipment

### 9.1 Dairy water supplies

Water is used for all cleaning purposes in a milk processing plant. An adequate supply of water of satisfactory bacteriological and chemical quality is therefore required. Water of good bacteriological quality is important to protect public health and to avoid contamination and possible deterioration in the quality of milk and milk products.

### 9.1.1 Bacteriological quality

The bacterial flora of most water supplies consists mainly of Gram negative rods.<sup>6</sup> Many of these may be proteolytic and lipolytic and will cause spoilage of milk and milk products if processing and storage conditions are not correct. Coliform bacteria, and in particular *Escherichia coli* type 1 which is largely of human and animal intestinal origin, are particularly undesirable in water. Their presence may indicate pollution of water by sewage and the possible presence of pathogenic bacteria.

The bacteriological quality of water varies with its source and it may also vary with the season of the year and variations in rainfall. Water of satisfactory bacteriological quality should meet the following requirements:

- total bacterial count at 37°C should not exceed 200 per ml
- coli-aerogenes (coliforms) bacteria should be absent in 1 ml
- nutrient gelatine count (proteolytic bacteria) at 21°C for three days should not exceed 500 per ml.

### 9.1.2 Chemical quality

Rain water is relatively pure and contains only traces of dissolved chemicals. The chemical impurities of a water supply are related to the topography and geology of the area from which it is obtained. Water may contain inorganic salts of calcium, magnesium and sodium as well as iron, copper, lead and zinc nitrate. The hardness of water is due mainly to the presence of inorganic salts of calcium and magnesium. There are two kinds of water hardness, temporary and permanent. Temporary hardness is due to the carbonates and bicarbonates of calcium and magnesium. These salts are easily precipitated or removed by heating; a typical example is the scale formation on the inside of a kettle. Permanent hardness is mainly due to the sulphates, chlorides and nitrates of calcium and magnesium. In the presence of certain alkalis these salts are converted into insoluble deposits and for this reason specific contituents, e.g. polyphosphates and salts of gluconic acid are incorporated into a detergent to minimise the precipitation.

It is usual to express water hardness in terms of equivalent calcium carbonate in ppm. Water supplies are classified as soft, moderately hard, hard and very hard if the total hardness (expressed as calcium carbonate) is 0–60, 60–120, 120–180 and over 180 ppm, respectively.

Deposits of calcium and magnesium salts on the surfaces of milk processing equipment reduces heat transfer efficiency and provides a nucleus for deposits of other materials present in milk. Hardness is also objectionable as it leads to waste of soaps and detergents.

Suggested chemical standards for water supplies are:

- total hardness (as CaCO<sub>3</sub>) less than 50 ppm
- chloride (as NaCl) less than 50 ppm
- pH 6.5 to 7.5

<sup>6.</sup> Microscopic examination of bacteria is carried out by placing bacteria on a glass slide and adding a simple stain, e.g. Methylene blue. The Gram stain is a differential staining procedure in the identification of bacteria. It was developed in 1884 by Christian Gram and is used to differentiate between bacterial genera. Bacteria are either Gram positive or Gram negative.

- lead 0.1 ppm maximum
- iron (as Fe) 1 ppm maximum
- cyanide 0.01 ppm maximum.

The presence of heavy metals such as copper and iron in a dairy water supply is particularly objectionable as they can act as catalysts in the oxidation of milk fat leading to off-flavours in products such as butter and cream.

### 9.1.3 Water softeners

Chemicals and zeolites or resins are used to soften water. Temporary hardness may be removed by the addition of lime or sodium hydroxide to the water while permanent hardness is removed by the addition of sodium carbonate and sodium hydroxide.

Thorough cleaning and sanitising of all dairy equipment is an essential part of milk processing. Water alone is inadequate for cleaning and sanitising and, therefore, chemical agents must be used.

Cleaning and sanitising dairy equipment is necessary to prevent:

- accumulation of undesirable micro-organisms in the equipment
- development of bad smells in the equipment which pass on to the product
- loss of efficiency in a dirty separator
- possible corrosion of metal parts due to lactic acid
- mould growth on wooden surfaces leading to mould contamination of the product and discolouration of the churn surface
- contamination of the product with pathogens.

Cleaning buttermaking equipment is dealt with in the section on buttermaking. This section discusses the principles of cleaning, sanitation and sterilisation of dairy equipment and the various treatments or chemicals used.

Processing equipment should be clean and the processing room should be well lit and ventilated, clean and tidy. However, sanitation of processing equipment means more than having the equipment looking clean and tidy.

The cleanliness of equipment can be classified at four levels:

- 1. Physical cleanliness, where all visible dirt has been removed.
- 2. Chemical cleanliness, where, in addition to all visible dirt, microscopically small residues have been removed.
- 3. Sanitation, where, in addition to being chemically clean, the equipment has been treated to inactivate or remove micro-organisms present on its surface.
- 4. Sterilisation, where, in addition to being sanitised, the equipment has been treated to destroy all micro-organisms present on the equipment.

Sanitation and sterilisation are easier to achieve if the equipment is initially at least physically clean. Therefore, the equipment is normally cleaned before sanitation or sterilisation.

### 9.2 Chemicals used for cleaning

Detergents are chemical agents that assist in the cleaning process by dissolving the deposited dirt, thereby making its removal easier. Sodium salts are the commonest and cheapest detergents. Sodium hydroxide, sodium carbonate and sodium tripolyphosphate are commonly used. Synthetic detergents, such as alkyl benzyl sulphate, and biological detergents are also used.

### 9.2.1 Sterilisers

Chemical sterilisers are agents which, when added to water at a specific concentration, reduce the number of micro-organisms on previously cleaned surfaces to very low levels. The active sterilising ingredient is usually iodine, chlorine, nitric acid or quaternary ammonium compounds. Organic sterilisers such as chloramine-T, halane and isocyanuric acids are also used.

### 9.3 Cleaning procedure

Before using any detergent or steriliser, remove as much of the dairy or food product as possible from the surface of the equipment.

- 1. Prewash the equipment with clean, cold water. This removes much of the dirt and should be carried out immediately after the product has been removed. Wash the equipment with warm water (50°C) to remove fatty material. If the equipment is washed thoroughly with water, much less detergent is required in later stages.
- 2. Wash the equipment with a detergent solution, following the manufacturer's instructions. The equipment should be cleaned thoroughly at this stage to ensure that it is chemically clean. The equipment should be scrubbed thoroughly using the detergent solution. Detergent cleaning also reduces bacterial numbers on the equipment.
- 3. Drain the detergent solution. It may be retained for washing other items of equipment, provided its strength is maintained. Rinse the equipment at least three times with clean cold water to remove all traces of the detergent. If not removed, traces of detergent may be incorporated in subsequent batches of dairy product. Rinsing three times with small volumes of water removes detergent residues much more effectively than rinsing once with a large volume of water.
- 4. Sanitise the equipment using one of the compounds mentioned above. Chlorine compounds are particularly corrosive and should only be used in accordance with the manufacturer's instructions. Rinse the equipment again with clean water to remove all residues of the sanitising agent. In the absence of a suitable chemical steriliser, the equipment can be scalded with water at 80°C.
- 5. Once washed and rinsed the equipment should be stored in a clean, dry, dust-free area.

Notes:

- Detergents and sterilisers are normally chemically active compounds and great care is required in their use and handling to avoid injury to personnel. If detergents or sterilisers come in contact with the eyes or sensitive parts of the body, rinse the affected parts thoroughly with clean water.
- Detergent sterilisers are compounds formulated to clean and sterilise equipment at the same time. They are generally expensive, but reduce the overall time required for cleaning and sterilising equipment and also reduce the amount of water needed for rinsing as only one set of rinsings are required.

# 10. Sampling and analysis of milk, milk products and water

Milk and milk product analysis is carried out to determine:

- freshness
- adulteration
- bacterial content
- milk constituents for payment calculation
- milk product composition.

### 10.1 Sampling

Milk processors usually pay for milk or cream on the basis of butterfat analysis, and a single butterfat test may be used to determine the butterfat content of thousands of litres of milk or cream. Therefore, an accurate and representative sample must be obtained.

Milk must be mixed thoroughly before sampling and analysis to ensure a representative sample. If the volume of milk is small, e.g. from an individual cow, the milk may be poured from one bucket to another and a sample of milk taken immediately. But if large volumes of milk are handled, the milk or cream must be mixed by stirring. However, it is very difficult to obtain a representative sample of milk or cream when a large volume is dumped into a large container. In such a case the milk must be stirred thoroughly and small samples taken from three or more places in the container. For best results, milk or cream must be sampled at temperatures between 15 and 32°C. If the cream is at a low temperature it will be thick and viscous and difficult to sample.

Sour milk or cream, in which casein has coagulated, must be sampled frequently. Sampling sour milk follows the same procedure as for fresh milk. If the milk or cream has been standing for a long time and a deposit has formed on the surface and sides of the container, it should be warmed while agitating before a sample is removed.

For certain analyses, milk samples can be preserved and stored. Samples of milk or cream for butterfat analysis can be preserved using formalin or potassium dichromate.

### 10.2 Milk pH

### 10.2.1 Measuring pH using indicator

A rough estimate of pH may be obtained using paper strips impregnated with an indicator. Paper strips treated with bromocresol purple and bromothymol blue are sometimes used at milk reception as a rejection test for milk. Bromocresol purple indicator strips change from yellow to purple between pH 5.2 and 6.0, while bromothymol blue indicator papers change from straw yellow to blue-green between pH 6.0 and 6.9.

### 10.2.2 Electrometric measurement of pH

Electrometric determination of pH depends on the potential difference set up between two electrodes when they are in contact with a test sample. A reference electrode whose potential is independent of the pH of the solution and an electrode whose potential is proportional to the hydrogen ion concentration of the test sample are used. Saturated calomel electrodes are usually used as reference electrodes, and glass electrodes are used to measure pH. Combined glass and calomel electrodes are also available.

Instruments which measure the current produced by the difference in potential between the glass and calomel electrodes are called pH meters (Figure 33).

#### Figure 33. pH meter.



#### Preparation of the pH meter

- 1. Read the pH meter instruction manual carefully.
- 2. The pH meter should be kept in a clean, dry atmosphere.
- 3. Before using a new glass electrode, or a glass electrode which has been stored for some time, soak it in N/10 HCl for about five hours.
- 4. Care should be taken not to scratch glass electrodes against the sides of beakers or other hard surfaces during storage or testing.
- 5. Check the level of saturated potassium chloride in the calomel electrode before making pH measurements. Crystals of potassium chloride should be present in the solution within the electrode.
- 6. Remove the rubber stopper or cap on the filling arm of the calomel electrode before making a test.

### Standardising and using the pH meter

- 1. Rinse the electrodes with distilled water and wipe them gently with tissue or filter paper.
- 2. Set the temperature; use the control knob to set the temperature of the buffer used to standardise the meter.
- 3. Standardise the pH meter against a buffer solution of known pH. Use a buffer solution with a pH as close as possible to that of the test solution.
- 4. Turn the range selector to the pH range covering the pH of the buffer control knob until the pointer of the meter reads the pH of the buffer.
- 5. Set the range switch to zero.
- 6. Rinse the electrodes with distilled water and dry them.
- 7. Set the temperature control knob to the temperature of the sample.
- 8. Place the test sample in position and allow the electrodes to dip into the solution.
- 9. Switch the range selector knob to the proper range and read the pH.
- 10. Rinse the electrodes after use and keep the electrode tips in distilled water between tests.

Always follow the manufacturer's instructions for the particular instrument.

### 10.3 Titratable acidity test

The production of acid in milk is normally termed "souring" and the sour taste of such milk is due to lactic acid. The percentage of acid present in milk is a rough indication of its age and the manner in which it has been handled. As mentioned earlier, fresh milk has an initial acidity due to its buffering capacity.

### 10.3.1 Using N/10 sodium hydroxide

#### Apparatus

- White enamelled or porcelain basin
- Stirring rod
- A 10 ml or 17.6 ml pipette
- Burette
- Burette-stand.

### Reagents

- One per cent alcoholic solution of phenolphthalein
- N/10 sodium hydroxide (NaOH) solution.

### Procedure

- 1. Fill the burette with N/10 NaOH and make sure there are no air bubbles trapped in the lower part.
- 2. Adjust the level of NaOH in the burette to the top mark, the lowest reading being at the upper end.
- 3. If milk, skim milk or buttermilk is to be tested, deliver 10 or 17.6 ml of milk into the porcelain dish. If cream is to be tested, use a 9 ml pipette (for cream weighing about 1 g/ml).
- 4. Add 3 to 5 drops of phenolphthalein to the sample in the cup.
- 5. Note the reading of the NaOH in the burette at the lowest point of the meniscus.
- 6. Allow the NaOH to flow slowly into the cup containing the sample and stir continuously. When a faint but definite pink colour persists, the end-point has been reached.
- 7. Take the reading of the burette at the lowest point of the meniscus. Subtract the first reading from the second to determine the number of millilitres of alkali (NaOH) required to neutralise the acid in the sample.

Calculation

Lactic acid (%) =  $\frac{\text{ml } N_{10} \text{ alkali} \times 0.009 \times 100}{\text{ml of sample}}$ 

### 10.3.2 Using N/9 sodium hydroxide

This test is for milk, skim milk and buttermilk. The apparatus used is the same as that used in 10.3.1.

### Reagents

- 1.6% alcholic solution of phenolphthalein
- N/9 sodium hydroxide.

### Procedure

- 1. Put 10 ml of milk in a porcelain dish using a pipette.
- 2. Add 0.5 ml of 1.6% solution of phenolphthalein.
- 3. Titrate with N/9 sodium hydroxide and follow the same procedures as in 10.3.1.

### Calculation

Lactic acid (%) = 
$$\frac{W}{V}$$

where: W = volume of N/9 NaOH required (ml)

V = volume of milk taken for analysis (10 ml)

### 10.3.3 Using N/9 sodium hydroxide

This test is used on cream. The apparatus and reagents are the same as those used in 10.3.1.

### Procedure

- 1. Put 10 ml of cream in a porcelain dish using a pipette.
- 2. Add 10 ml of water with the same pipette.
- 3. Add 0.5 ml of 1.6% phenolphthalein.
- 4. Titrate with N/9 NaOH.
- 5. Calculate as in 10.3.2.

For determination of acidity of cream serum, the fat percentage of the cream should be known, and the calculation is as follows:

Acidity of serum =  $\frac{\text{acidity of cream} \times 100}{100 - \% \text{ fat}}$ 

### **10.4 Alcohol test**

The alcohol test, together with the acidity test, is used on fresh milk to indicate whether it will coagulate on processing. Milk that contains more than 0.21% acid, or calcium and magnesium compounds in greater than normal amounts, will coagulate when alcohol is added.

### Apparatus

- Test tubes, e.g. 150 mm long and 16 mm diameter
- Test-tube racks or blocks of wood with holes bored to hold the test tubes.

### Reagents

75% alcohol solution. This is usually prepared from 95% alcohol by mixing with distilled water in the proportion of 79 parts of 95% alcohol to 21 parts of distilled water.

### Procedure

- 1. Put equal volumes of milk and 75% alcohol in a test tube.
- 2. Invert the test tube several times with the thumb held tightly over the open end of the tube.
- 3. Examine the tube to determine whether the milk has coagulated. If it has, fine particles of curd will be visible.

### 10.5 Clot-on-boiling test

Acidity decreases the heat stability of milk. The clot-on-boiling test is used to determine whether milk is suitable for processing, as it indicates whether milk is likely to coagulate during processing (usually pasteurisation). It is performed when milk is brought to the processing plant—if the milk fails the test it is rejected.

The test measures the same characteristics as the alcohol test but is somewhat more lenient (0.22 to 0.24% acidity, as opposed to 0.21% for the alcohol test). It has the advantage that no chemicals are needed. However, its disadvantage is that at high altitude milk (like all liquids) boils at a lower temperature and therefore the test is even more lenient.

### Apparatus

- One boiling water bath (a 600 ml beaker on a gas or electric heater is adequate)
- Test tubes
- Timer (a watch or clock is adequate).

#### Procedure

- 1. Place about 5 ml of milk in a test tube (the exact amount is not critical) and place the test tube in boiling water for 5 minutes.
- 2. Carefully remove the test tube and examine for precipitate.

The milk is rejected if any curd forms.

### 10.6 Fat determination

The main tests used to determine the fat content of milk and milk products are the Gerber (Europe) and Babcock (USA) tests. Automated methods for testing milk are now used in central laboratories and at large processing centres.

Fat in milk exists in the form of an emulsion which is stabilised by phospolipids and proteins. The theory of the Gerber method is based on the fact that the fat globules are de-emulsified by the addition of concentrated sulphuric acid ( $H_2SO_4$ ). The free fat, with a lower density than the surrounding medium, may be separated rapidly by centrifugal force. Amyl alcohol addition gives a clearer dividing line on the butyrometer scale between the fat layer and the other material. While the Rose Gottlieb ether extraction method is the recognised standard procedure for the determination of fat in milk and dairy products, the Gerber method gives results which are in agreement with those of the Rose Gottlieb.

The procedures outlined below are used to determine the butterfat content of milk, skim milk, buttermilk, cream and whey.

### 10.6.1 Milk

Apparatus (Figure 34)

- Gerber butyrometer calibrated to read 0-8% or 0-5% and graduated at 0.1% intervals
- Butyrometer stoppers
- Milk pipette volume to match the butyrometer in use
- 10 ml double-bulb pipette\* for pipetting sulphuric acid
- 1 ml bulb pipette\* for pipetting amyl alcohol
- Thermometer to read 1–100°C
- Water bath
- Gerber centrifuge
- \* Alternatively, automatic dispensers (Figure 34b) can be used for delivering 10 ml of sulphuric acid and 1 ml of amyl alcohol.

#### Reagents

- Sulphuric acid (density of  $1.815 \text{ g/ml} \pm 0.002$ )
- Amyl alcohol (density between 0.810 and 0.812 g/ml).

#### Procedure

- 1. Mix the milk sample (temperature about 20°C) thoroughly, taking care to minimise incorporation of air. Allow the sample to stand for a few minutes to discharge any air bubbles. Mix gently again before pipetting.
- 2. Pipette or dispense 10 ml of sulphuric acid into the butyrometer.
- 3. Pipette the required volume of milk into the butyrometer. Care must be taken to avoid charring the milk, by ensuring that the milk flows gently down the inside of the butyrometer.

It then rests on top of the acid (Figure 35).

4. Pipette or dispense 1 ml of amyl alcohol.

Figure 34. Apparatus for the Gerber test: (a) Various stoppers for the butyrometer; (b) alcohol and acid dipsensers; (c) butyrometer shaking stand with cover; (d) and (f) Gerber centrifuges; (e) water bath.













- 5. Clean the neck of the butyrometer with tissue or dry cloth.
- 6. Stopper the butyrometer tightly using a clean, dry stopper. Shake and invert the butyrometer several times until all the milk has been absorbed by the acid.
- 7. Place the butyrometer in a water bath at  $65^{\circ}$ C for 5 minutes.
- 8. Centrifuge for 4 minutes at 1100 rpm.
- 9. Return the butyrometer to the water bath for 5 minutes. Ensure that the water level is high enough to heat the fat column.
- 10. Read the fat percentage by bringing the graduation mark to eye level (Figure 35). If necessary, the fat column can be adjusted by regulating the position of the stopper.

Figure 35. (a) Transferring milk to the butyrometer; (b) reading the fat result from the butyrometer.



### Hazards

- Sulphuric acid is toxic, highly corrosive and will also cause severe burning if it comes in contact with the skin or eyes.
- When mixing the butyrometer contents, considerable heat is generated.
- If the stopper is slightly loose, leakage may occur during mixing, centrifuging or holding in the water bath.

#### Precautions

- Wear protective eye goggles.
- Avoid all spillage and drops of sulphuric acid from acid dispensers.

- When mixing, hold the butyrometer stopper firmly to ensure that it cannot slip. Use a cloth or glove to protect the hands when mixing.
- Do not point the butyrometer at anyone when mixing.

### 10.6.2 Skim milk, buttermilk and whey

### Apparatus

- Standard Gerber butyrometers designed for testing skim milk
- The rest of the apparatus is the same as that used for whole milk.

### Reagents

The same reagents are required as for whole milk.

### Procedure

- 1. Follow the same procedure as for whole milk up to and including the first centrifuging.
- 2. Place the butyrometers in the water bath at 65°C, stoppers down, for 1 to 2 minutes.
- 3. Centrifuge for 4 to 5 minutes.
- 4. Place in the water bath for 2 to 3 minutes and read. A check reading is made after they are placed in the water bath for 2 to 3 minutes.

The readings obtained must be corrected as follows:

Percentage read on	
the butyrometer	Correction
< 0.10%	Add 0.05%
0.10 - 0.25%	Add 0.02%
> 0.25%	No correction required

### 10.6.3 Cream

### Apparatus

As for whole milk except for the following:

- Gerber cream butyrometer
- 5 ml bulb pipette
- Balance with holders for butyrometers
- Wash bottle with warm (30–40°C) distilled water.

### Reagents

The same as for whole milk.

### Procedure

- 1. Mix the sample thoroughly, though cautiously, to avoid frothing. If the sample is very thick, it should be warmed to between 37.8 and 50°C to facilitate mixing.
- 2. Weigh 5 g of cream into the butyrometer.
- 3. Add about 6 ml of warm distilled water from the wash bottle.
- 4. Add 10 ml of sulphuric acid and 1 ml of amyl alcohol.

The remaining procedures are the same as for whole milk.

### 10.6.4 Cheese

Fat determination in cheese is carried out in a similar manner to that for milk.

### Apparatus

- Gerber cheese butyrometer stamped "3 g cheese"
- Grease-proof paper.

Other apparatus is the same as for Gerber milk-fat analysis.

#### Reagents

- Distilled water
- Sulphuric acid
- Amyl alcohol.

#### Procedure

- 1. Weigh out 3±0.01 g of cheese on a piece of greaseproof paper.
- 2. Dispense 10 ml sulphuric acid into the butyrometer. Carefully add 3 ml of water so that it rests on the acid.
- 3. Wrap the 3 g of cheese in greaseproof paper to form a cylinder that fits into the butyrometer.
- 4. Add a further 4–5 ml of water.
- 5. Add 1 ml of amyl alcohol.
- 6. Stopper the butyrometer securely and shake to dissolve the cheese. It may be difficult to dissolve the cheese. If so, place the butyrometer in the heated water bath and remove periodically for mixing until the cheese is fully dissolved.
- 7. Centrifuge the butyrometers and read as for milk and cream.

### Causes of unsatisfactory tests with the Gerber method

Incomplete separation of the fat and aqueous phases may be caused by:

- impure or incorrect amounts of amyl alcohol
- below strength sulphuric acid
- using acid or milk at low temperatures.

Charred material in the fat column may be caused by:

- too strong or too much sulphuric acid
- using acid or milk at high temperatures
- using dirty or burnt rubber stoppers.

Other factors affecting the accuracy of the Gerber test include incorrect centrifuge speed and incorrect temperature of reading the test.

### 10.7 Specific gravity of milk

Specific gravity is the relation between the mass of a given volume of any substance and that of an equal volume of water at the same temperature.

Since 1 ml of water at 4°C weighs 1 g, the mass of any material expressed in g/ml and its specific gravity (both at 4°C) will have the same numerical value. The specific gravity of milk averages 1.032, i.e. 1 ml of milk weighs 1.032 g at 4°C.

Since the mass of a given volume of water at a given temperature is known, the volume of a given mass, or the mass of a given volume of milk, cream, skim milk etc can be calculated from its specific gravity. For

example one litre of water at  $4^{\circ}$ C has a mass of 1 kg, and since the average specific gravity of milk is 1.032, one litre of average milk will have a mass of 1.032 kg.

### Apparatus

• Lactometer (Figure 36) — this is a hydrometer (a device for measuring specific gravity) adapted to the normal range of the specific gravity of milk. It is usually calibrated to read in lactometer degrees (L) rather than specific gravity *per se*.





The relationship between the two is:

 $\frac{L}{1000} + 1 = \text{specific gravity (sp. gr.)}$ Thus, if L = 31, specific gravity = 1.031

- A tall, wide glass or plastic cylinder
- A thermometer (the lactometer may have a thermometer incorporated).

### Procedure

- 1. Heat the sample of milk to  $40^{\circ}$ C and hold for 5 minutes. This is to get all the fat into a liquid state since crystalline fat has a very different density to liquid fat, and fat crystallises or melts slowly. After 5 minutes, cool the milk to  $20^{\circ}$ C.
- 2. Mix the milk sample thoroughly but gently. Do not shake vigorously or air bubbles will be incorporated and will affect the result.
- 3. Place the milk in the cylinder. Fill sufficiently so that the milk will overflow when the lactometer is inserted.
- 4. Holding the lactometer by the tip, lower it gently into the milk. Do not let go until it is almost at rest.
- 5. Allow the lactometer to float freely until it is at rest. Read the lactometer at the top of the meniscus. Immediately, read the temperature of the milk; this should be 20°C. If the temperature of the milk is between 17 and 24°C, the following correction factors are used to determine L:

Temp℃	17	18	19	20	21	22	23	24
Correction	-0.7	-0.5	-0.3	0	+0.3	+0.5	+0.8	+1.1

For example if the lactometer reading is 30.5 and the temperature is 23 °C:

corrected lactometer = Lc = 30.5 + 0.8 = 31.3

#### Calculations

Calculations always use Lc, the corrected lactometer reading. To calculate the specific gravity, divide the corrected lactometer reading by 1000 and add 1.

In our example: Sp. gr. =  $\frac{31.3}{1000} + 1 = 1.0313$ 

### 10.8 Total solids (TS) in milk

Knowledge of the total solids and solids-not-fat (SNF) content of milk is necessary when it is sold for liquid consumption or manufactured into products such as butter, cheese, and milk powders.

In most countries, milk offered for sale for liquid consumption must conform to certain legal standards with regard to its total solids content, e.g. minimum 3% fat and 8.5% solids-not-fat.

The yield of dairy products obtained from milk will depend on the amount of constituents (total solids) present. The greater the amount of fat and protein in milk the greater the yield of cheese, and milk with a high fat content gives more butter than milk with a lower fat content.

### 10.8.1 Lactometer method

The total solids content of milk is the total amount of material dispersed in the aqueous phase, i.e. SNF = TS - % fat.

The only accurate way to determine TS is by evaporating the water from an accurately weighed sample. However, TS can be estimated from the corrected lactometer reading. The results are not likely to be very accurate because specific gravity is due to water, material less dense than water (fat) and material more dense than water (SNF). Therefore, milk with high fat and SNF contents could have the same specific gravity as milk with low fat and low SNF contents.

$$TS = \frac{Lc}{4} + (1.22 \text{ x fat \%}) + 0.72$$
  
SNF = TS - fat %  
or =  $\frac{Lc}{4} + (0.22 \text{ x fat \%}) + 0.72$ 

It should be noted that the relationship between Lc and TS varies from country to country depending on milk composition. The above formulae are called the Richmond formulae and were calculated for Great Britain.

### 10.8.2 Oven-drying method

#### Principle of method

A known weight of milk is dried at a constant temperature to a constant weight. The weight of the residue after drying is the weight of the total solids.

#### Apparatus

- Analytical balance with a readability of 0.1 mg
- Desiccator
- Drying oven, thermostatically controlled at 10–22°C
- Metal dishes about 2 cm deep and 6–8 cm in diameter with well-fitting lids
- Water bath
- Pipette.

#### Procedure

- 1. Dry the dish and the lid in the oven at 102±2°C for at least 1 hour. Allow the dish with the lid on to cool to room temperature in a desiccator. Weigh the dish and the lid to the nearest 0.1 mg.
- 2. Warm a representative sample of milk to 20±2°C. If the milk sample contains pieces of churned fat heat it to 40°C to liquefy the fat, mix gently and cool to 20±2°C.
- 3. Pippette 3 ml of the milk into the dish, cover the dish and weigh.
- 4. Uncover the dish and place it in a boiling water bath for 30 minutes. Dry in the drying oven at 102± 2℃ for 2 hours with the lid placed beside the dish.
- 5. Cover the dish, remove from the oven and allow to cool to room temperature in the desiccator and weigh.
- 6. Dry in the oven for 1 hour as before. Cool and reweigh. Repeat the drying until the difference in weight between two successive weighings is not more than 1 mg.
- 7. The total solids content, expressed as a percentage by mass is equal to:

$$\frac{M_2 - M_0}{M_1 - M_s} \ge 100$$

where:

 $M_0 =$  the mass, in grams, of the dish and lid

 $M_1$  = the mass, in grams, of the dish, lid and test portion

 $M_2$  = the mass, in grams, of the dish, lid and dried test portion

### 10.9 Formaldehyde in milk

Preservatives are chemical substances which inhibit or retard bacterial growth. Milk offered for sale must not contain preservatives. To extend its shelf-life and to disguise unhygienic production conditions milk producers may add a preservative, e.g. formaldehyde to milk.

### Apparatus

• Test tubes graduated at the 10 ml mark.

### Reagents

- 10% ferric chloride solution
- Gerber sulphuric acid.

### Procedure

- 1. Take about 5 ml of milk in a test tube and dilute with an equal volume of water.
- 2. Add a drop of a 10% solution of ferric chloride to 10 ml of Gerber sulphuric acid.
- 3. Gently pour the acid down the side of the test tube.

The presence of formaldehyde is indicated if a violet/blue colour appears at the junction of the sulphuric acid and milk. In the absence of formaldehyde, milk gives a green tinge at the sulphuric acid milk junction, which changes to a brown colour on standing.

The test will detect 1 ml of 40% formaldehyde in about 95 litres of milk, i.e. about 10 ppm.

### 10.10 The methylene blue reduction test

The length of time milk takes to decolourise methylene blue is a good measure of its bacterial content and hence of its hygienic quality. This time period is governed primarily by the activity of the reducing bacteria present in the milk plus the oxygen content. When the oxygen has been utilised the methylene blue is reduced, changing in colour from blue to white.

#### Apparatus

- A water bath at 37–38°C
- Test tubes graduated at the 10 ml mark. The tubes should be plugged with cotton wool or closed with aluminium caps and sterilised before use
- A supply of 1 ml pipettes (bacteriological type) also plugged with cotton wool and sterilised
- A thermometer, 0–100°C graduated at 0.5°C intervals
- A supply of sterilised rubber stoppers for closing the tubes when the samples have been put into them. These can be conveniently sterilised before use by immersing in boiling water for 10 minutes
- A methylene blue solution made up from standard methylene blue milk testing tablets which are available commercially. The procedure specified by the manufacturer of the tablet should be strictly observed
- Test-tube racks.

### Procedure

When the test is used to grade suppliers' milk the samples are taken in the milk reception area.

- 1. Mix the supplier's milk thoroughly.
- 2. Take the sample with a clean, sterile dipper and fill the test tube to the 10 ml mark.
- 3. Stopper the test tube with a sterile rubber stopper and mark the milk supplier's number on the tube.
- 4. Place the test tube in the test tube rack.
- 5. When sufficient samples to fill the test tube rack have been collected, add 1 ml of the methylene blue solution to each test tube. Replace the rubber stopper with aseptic precautions.
- 6. Invert each tube twice, to mix the milk and solution thoroughly, and place the tubes in the water bath at a temperature of 37–38°C.
- 7. Make a note of the time at which the tubes are put into the water bath.
- 8. Examine the samples after 30 minutes, note the numbers of decolourised samples and remove them from the bath. Do not disturb partly decolourised tubes. Invert all other tubes.
- 9. At half-hourly intervals examine again for decolourised samples and repeat as above.

### Remarks

Include two control tubes with each batch consisting of:

- (a) 10 ml of mixed milk plus 1 ml of methylene blue solution.
- (b) 10 ml of mixed milk plus 1 ml of water.

Immerse both tubes in boiling water for 3 minutes to destroy the natural reduction action of the milk. Comparison of tests with (a) will show when decolourisation is beginning and comparison with (b) will show when it is complete.

The dipper used for taking samples may be conveniently sterilised after taking each sample by rinsing in clean water and then dipping into a pail of boiling water for about 30 seconds.

### Interpretation of results

Time taken to decolourise	Milk grade	
< 30 minutes	Very bad	
30 minutes to 1 hour	Bad	
1 to 2 hours	Poor	
2 to 4 1/2 hours	Fair	
> 4 1/2 hours	Good	

It is not necessary to test all individual milk suppliers on the same day. When the milk of any supplier is tested three or four times over a period of a month a very good indication of the care and cleanliness exercised in its production is obtained.

### 10.11 Resazurin 10-minute test

This test is based on the reduction of the oxidation/reduction indicator resazurin to resorufin and finally to dihydroresorufin. Resazurin imparts a blue colour to milk which when reduced to resorufin changes to pink and finally to white when reduced to dihydroresorufin. The test is a good indicator of the bacteriological quality of milk. The test may be used at the milk reception and milk of doubtful quality may be held back until the results of tests are known.

#### Apparatus

- A water bath similar to that specified for the methylene blue test
- Stainless steel dipper for milk sampling
- Test tubes with a graduation mark at 10 ml
- Test tube racks
- 1 ml bacteriological type sterile pipettes
- Rubber stoppers sterilised before use by immersing in boiling water for 10 minutes
- A Lovibond comparator with a Resazurin disc.

#### Reagent

• A standard solution of resazurin (0.005%).

#### Procedure

- 1. Mix the milk thoroughly before taking the sample.
- 2. Take the sample with a clean, sterile dipper and fill the test tube to the 10 ml mark.
- 3. Cork the tube with a rubber stopper and mark the test tube with the supplier's number.
- 4. Place the test tube in the test tube rack.
- 5. Remove the stoppers and add 1 ml of 0.005% resazurin solution to each test tube. Replace the stoppers and invert each test tube twice.
- 6. Place the rack with the test tubes in the water bath at 37°C and record the time.
- 7. After 10 minutes in the water bath, take the tubes out and transfer each in turn to the Lovibond comparator.
- 8. Place a tube of mixed milk without resazurin in the comparator disc as a series of standards. Revolve the disc until the colour of the sample under test is matched by one of the standards.
- 9. Note the number of this colour which indicates the quality of the milk as per the following:

Colour number	<u>Milk quality</u> Satisfactory	
4 and over		
3 1/2 to 1	Doubtful	
1/2 or 0	Unsatisfactory	

#### Remarks

The colour developed at the end of the holding period depends mainly on the number of micro-organisms present and on their colour reducing properties. It is also affected by the number of leucocytes in the milk.

The test does not give as good an indication of the quality of milk as the methylene blue test but the results can be obtained more rapidly.

### 10.12 Sediment or visible dirt test

This is a test for insoluble dirt in milk and may indicate the degree of sanitary care taken during production. The test consists of straining a quantity of milk through a cotton pad and observing the amount and type of residue remaining. If milk delivered to a processing centre is to be graded or categorised according to the sediment test then reference cotton pads can be made by straining milks containing different quantities of visible dirt through filter pads.

While the sediment test is a good means of demonstrating the presence of visible (insoluble) dirt it does have limitations:

- the presence or absence of a residue does not necessarily indicate the bacteriological quality of the milk
- the test is valueless if the milk has been carefully strained before delivery to the processing centre and such milks may be classified as satisfactory even though they may contain high bacterial numbers
- erroneous results may be obtained if the milk supply is not well mixed and a representative sample taken.

### 10.13 Moisture content of butter

Butter varies in composition, e.g.

Butterfat (%)	80-85
Water (%)	12–16
Salt (%)	0–2
Curd or casein (%)	0.5–1

The food value of butter depends on its butterfat content. The fat content of butter is reduced by the incorporation of excess water and most countries protect the consumer by prescribing a legal limit for water content.

### Apparatus

- Aluminium, platinum, nickel or porcelain cup, flat-bottomed, about 3 cm in diameter, and not less than 2.5 cm deep, with a spout
- A glass stirring rod with widened flat end
- A spoon or steel blade
- A butter trier
- Alcohol lamp or other means of heating the sample
- Analytical balance with a readability of 1 mg
- Iron tripod
- Asbestos-centre wire gauze.

### Procedure

- 1. Weigh 10 g of butter into the cup. Heat the butter over a low flame until it ceases foaming and a light-brown colour appears. When heating the sample, place the container on the asbestos-centre wire gauze on a tripod. This distributes the heat evenly across the bottom of the cup.
- 2. After the moisture is driven from the butter, allow the sample to cool and reweigh.

### Calculations

Percentage moisture content of the butter is calculated as:

Moisture 
$$\% = \frac{\text{original weight} - \text{final weight}}{\text{original weight}} \ge 100$$

### 10.14 Salt content of butter

Controlling and monitoring the composition of butter is necessary to determine the production efficiency of milk processing. The composition and quality of butter may be determined by legal and market requirements. Some markets (customers) require butter without salt and others require various salt contents up to a maximum of 2%. The more moisture and salt that can be incorporated into butter, within legal and customer requirement limits, the more efficient and profitable the milk-processing enterprise.

The usual method of analysis for salt (NaCl) is by titration using silver nitrate. The end point of the titration is determined colorimetrically using potassium chromate as indicator.

The equation of the reaction is

NaCl + AgNO<sub>3</sub> — AgCl + NaNO<sub>3</sub>.

When excess  $AgNO_3$  is present it reacts with the potassium chromate indicator giving a red colour and this is the titration end point.

### Apparatus

- Burette, 50-ml capacity with 0.1 ml subdivisions
- A 50 ml conical flask or beaker or aluminium cup.

### Reagents

- 4% potassium chromate in water (W/W)
- A standard silver nitrate solution. If 10 g of butter are used a convenient strength of silver nitrate is a solution containing 29.06 g AgNO<sub>3</sub>/litre. One ml of this solution corresponds to 0.1% salt.

### Procedure

- 1. Weigh 10±0.1 g butter in a suitable container, e.g. an aluminium cup or use the residue after determination of moisture content.
- 2. Add about 100 ml of hot distilled water.
- 3. Add 10–15 drops of potassium chromate and titrate while mixing until a permanent faint red colour is obtained.
- 4. The number of ml of AgNO3 added divided by 10 gives the per cent salt in the butter.

# 10.15 Determination of protein content of milk by formaldehyde (formal) titration

When formaldehyde is added to milk the free amino groups of the protein react with the carbonyl groups of formaldehyde causing the milk to become acidic. The acidity developed is related to the amount of protein present which may be measured by titrating with sodium hydroxide (NaOH) using phenolphthalein as indicator.

### Apparatus

- White porcelain evaporating basin, 30 ml capacity
- Burette, 50 ml capacity with 0.1 ml subdivisions
- Pipette, 10 ml capacity with 0.1 ml subdivisions
- A glass stirring rod.

### Reagents

- Saturated aqueous potassium oxalate
- 0.5% phenolphthalein solution
- N/9 sodium hydroxide
- 40% formalin solution.

### Procedure

- 1. Place 10 ml of milk in a white porcelain basin
- 2. Add 0.4 ml of saturated aqueous potassium oxalate and 0.5 ml of 0.5% phenolphthalein solution.
- 3. Allow to stand for 2 minutes and titrate with N/9 NaOH until a pink colour is obtained.
- 4. Add 2 ml of neutral 40% formalin which will discharge the pink colour.
- 5. Continue the titration with N/9 NaOH until a pink colour of equal intensity is again obtained.
- 6. The number of ml of the N/9 NaOH used after the addition of the formalin multiplied by 1.74 gives the percentage protein in the milk.

The formalin solution is made neutral by adding a few drops of phenolphthalein and then adding sodium hydroxide drop by drop until a faint pink colour is obtained.

If the percentage case in in the milk is required multiply the titration figure obtained in step 6 above by 1.38.

### 10.16 Estimation of hardness in water

### 10.16.1 Temporary hardness

#### Apparatus

- Conical flask, 250 ml capacity
- Burette, 50 ml capacity with 0.1 ml subdivisions
- Bunsen burner
- Tripod stand and wire gauze.

#### Reagents

- Methyl red indicator, 0.1% in ethanol
- N/50 sulphuric acid.

#### Procedure

- 1. Take 100 ml of water in a flask and add a few drops of methyl red indicator.
- 2. Titrate with N/50  $H_2SO_4$  until the colour changes to red. The acid decomposes the carbonates and bicarbonates.
- 3. Boil to drive off the carbon dioxide. During boiling the red colour disappears.
- 4. Continue titration with the acid and boiling until the red colour is permanent.

Each ml of acid used is equivalent to 10 parts of calcium carbonate per million parts of water (10 ppm).

### 10.16.2 Permanent hardness

#### Apparatus

- White porcelain evaporating basin, 190 ml capacity
- Burette, 50 ml capacity with 0.1 ml subdivisions
- Bunsen burner
- Tripod stand and wire gauze.

### Reagents

- N/50 sodium carbonate
- N/50 sodium hydroxide
- N/50 sulphuric acid
- Methyl red indicator, 0.1% in ethanol.

#### Procedure

- 1. Take 100 ml of water in a porcelain basin.
- 2. Add 12.5 ml each of N/50 Na<sub>2</sub>CO<sub>3</sub> and N/50 NaOH. Calcium is precipitated by the sodium carbonate as calcium carbonate and magnesium is precipitated by the sodium hydroxide as magnesium hydroxide.
- 3. Evaporate until almost dry.
- 4. Wash with freshly boiled hot distilled water on to a filter paper and wash the precipitated material thoroughly.
- 5. Titrate the filtrate with N/50 H<sub>2</sub>SO<sub>4</sub> using a few drops of methyl red as indicator.
- 6. Repeat the procedure on 100 ml of distilled water.
- 7. From the difference between the number of ml of the acid used for water and distilled water calculate the permanent hardness as parts of CaCO<sub>3</sub> in one million parts of water. Each ml of N/50 H<sub>2</sub>SO<sub>4</sub> is equivalent to 10 ppm CaCO<sub>3</sub>.

The total hardness of water is equal to the temporary plus the permanent hardness.

### 10.16.3 Water-testing tablets

These tablets are supplied by Fisons Scientific Equipment (see Appendix XIII).

In addition to the laboratory methods described above water testing tablets are ideal for quick and reliable testing in the field. They are crushed in the water sample until a colour change occurs and the number required allows results to be calculated in ppm. Magnesium hardness is the difference between total and calcium hardness. Permanent hardness is the difference between total hardness and total alkalinity.

### Total alkalinity tablets

For carbonate and hydroxide ions. Results are expressed in PPM of calcium carbonate.

### Calcium hardness tablets

For calcium ions. Results are expressed in ppm of calcium carbonate.

### **Total hardness tablets**

For calcium and magnesium ions. Results are expressed in ppm of calcium carbonate.

It is important that the supplier's instructions are followed carefully.

## 11. Dairy building design and construction

This section gives guidelines for the construction of a simple building suitable as a dairy processing room for handling up to 500 litres of milk per day.

### **11.1 Site selection**

The following aspects should be considered when selecting a site for the dairy processing room:

- water supply and quality
- milk catchment supply area
- land availability, drainage and quality
- proximity of other buildings and activities
- proximity to a road
- effluent disposal
- good drainage.

### 11.1.1 Water supply

Water serves many functions in a dairy, such as washing, indirect heating, cooling milk and adjusting product composition. Water comes into direct contact with the product. It is important, therefore, to locate the dairy near a plentiful supply of clean water. Water can be collected from the roof of a dairy building or nearby barns by putting guttering around the roof and directing the water to a storage tank.

### 11.1.2 Land

When selecting a site one should allow for possible future expansion. The site should be well drained and not susceptible to subsidence.

### 11.1.3 Other buildings

It is important to locate the dairy correctly in relation to other buildings. It should not be located near a hay barn or animal feed store where mould spores and dust are present as they can contaminate the raw material and products. It should also be located away from other sources of contamination such as dung heaps or cattle assembly areas to avoid bad odours and flies.

### 11.1.4 Proximity to the road

For convenience in collecting milk and for product distribution, the dairy should be located near a road. However, if the building is too near the road dust contamination will be a problem. Therefore, the doors and windows should not face the road. Windows for letting in light only can face the road.

### 11.1.5 Effluent disposal

The satisfactory disposal of effluent from the dairy is important. Since most effluent comes from washing and from spillage, it can be minimised by careful product recovery, proper processing practice and care to avoid spillages. Rinsings and wash water should be piped away from the building for a distance of at least 15 m and directed into a soak pit. Raw effluent should not be piped directly into a river or stream. If the effluent is not piped away from the building it will become a source of contamination and foul smells.

### 11.2 Type of building

A simple building of 25  $\text{m}^2$  internal floor area is adequate for processing at the scale being discussed. An additional room of 10  $\text{m}^2$  floor area is desirable for use as a product store and office.

### **11.2.1 Construction materials**

The foundation and floor should be constructed from stone and concrete. If wood is used it should be treated to prevent damage by termites and water. The material for the superstructure is best chosen according to availability and cost. The dairy can be made from basic materials and does not need extravagant construction.

#### Floor

Where possible, all floors should be constructed of concrete with cement surfacing. The floor should slope (1-1.5%) to one end to facilitate drainage and cleaning. The cement should continue up the internal walls (curved at the junction of the floor and wall) for at least one metre if the superstructure of the building is not constructed from concrete.

### **Effluent** piping

The sloped floor drains to an outlet. Effluent should be piped from the outlet to a soak pit through concrete pipes 10 cm in diameter.

### Light

One or two screened windows (total area,  $3.5 \text{ m}^2$ ) should be installed to permit the operation of the dairy without artificial light. The windows can also be used for ventilation, but should be screened with mesh to reduce the number of insects entering the building.

### Ceiling

Where possible, a ceiling should be included to reduce contamination and dust from the roof. This will help to improve the hygiene of the building and also keep the inside cool. A ceiling can be made of sacking or other cloth material. Other ceiling materials, e.g. chipboard, fire resistant materials, may be expensive and difficult to obtain.

### Door

The main door should be wide enough to allow for equipment installation and easy access of personnel with milk cans etc.

### 11.3 Arrangement and installation of equipment

### 11.3.1 Arrangement

When arranging equipment one must consider:

- hygiene and safety of operation
- the flow of raw material through to product, i.e. process sequence
- access to each item of equipment for operation, cleaning and storage
- storage and sale of product
- disposal of by-product.

### 11.3.2 Installation

Some equipment must be securely fixed. The cream separator should be mounted on a level stand fixed firmly to the floor and should be at a convenient height for working. Once the separator is mounted on the stand the level should be checked with a spirit level before final tightening of the fixing screws. Similarly,

the churn stand and butter-working table should be fixed. Cheese vats of the necessary capacity are portable and can be located as desired. The fixing block for a lever-action cheese press should be fixed firmly to the wall.

If the water supply permits it, two hose points should be installed on opposite walls to facilitate cleaning. Electric wiring and installation of electrical equipment should be carried out by qualified personnel.

## Appendix I

### **Dairy calculations**

The following calculations and formulae will be useful in the operation of a milk collection and processing centre.

1. Calculate the value of 1 kg of butterfat from the known price of butter, e.g. EB 25 (1 US\$ = EB 6). Butter comprises 80% butterfat. Therefore, the price of 1 kg butterfat is:

$$\frac{25 \times 100}{80}$$
 = EB 31.25

- 2. Calculate the value of 1 litre of skim milk. Cottage cheese made from fermented skim milk has a value of EB 3.00/kg. If we assume an average yield of 1 kg cottage cheese from 9 litres of skim milk, each litre of skim milk has a value of about 33 cents.
- 3. Calculation of the value of milk received. Assume the producer delivers 100 litres of milk containing 4% butterfat.
- 3.1. Calculate the weight and value of butterfat received. The specific gravity of milk is about 1.032 kg/litre.

Therefore the weight of milk received is:

100 litres x 1.032 = 103.2 kg

The weight of fat received is:

103.2 x 4.0 100 = 4.128 kg

The value of the butterfat purchased from the producer is:

4.128 x EB 31.25 = EB 129.00

3.2. Calculate the volume and value of the skim milk. It is assumed that about 90% of the whole milk which is separated is recovered as skim milk. In this case, we therefore recover 90 litres of skim milk with a value of 33 cents/litre.

The value of skim milk is:

90 x 0.33 = EB 29.70

3.3. To obtain the total value of the milk received, add the values obtained in 3.1 and 3.2.

EB 129.00		for butterfat
Total	EB 29.70 FB 158 7	for skim milk

Therefore, the average value of 1 litre of milk is EB 1.59.

In large scale dairy plants with a range of products, payment may be made on the basis of total solids or on the basis of fat and protein contents.

In arriving at the price paid to the producer milk collection costs, the processing costs and the costs associated with the distribution and sale of the products must be taken into account. Depreciation costs of equipment and buildings must also be taken into account.

4. Calculation of produce or butter ratio. In the above example 103.2 kg of milk were received from the producer and if we assume that 4.8 kg of butter were made from this milk then the produce or butter ratio is:

 $103.2 \div 4.8 = 21.5$ 

i.e. 21.5 kg of milk were required to make 1 kg of butter

5. Calculation of overrun. Overrun has been defined as the difference between the number of kilograms of butterfat churned and the number of kilograms of butter made. Using the values obtained above the overrun is:

4.8 - 4.128 = 0.672

Overrun is usually expressed as a percentage, i.e. the excess of butter made over butterfat used per 100 kg of butterfat:

$$\frac{4.8-4.128}{4.128} \ge 100 = 16.3\%$$

The efficiency of operation of the processing plant is affected by all stages from milk weighing, sampling and testing to processing conditions and is reflected in the values obtained for produce and overrun. A high produce or butter ratio figure or a low overrun figure indicate inefficiencies and possibly carelessness by the operatives.

6. The effect of butter composition on profitability. Legal compositional standards for butter are a minimum of 80% butterfat and a maximum of 16% moisture. Other constituents in butter include salt and curd or protein. For maximum efficiency a butter-producing plant should operate as closely as possible to these legal requirements.

Let us compare the efficiency of two dairies:

Dairy A produces butter with 80% fat.

Dairy B produces butter with 83% fat.

If each Dairy processes 100 kg fat then,

Dairy A produces  $100 \div 0.80 = 125$  kg butter and

Dairy B produces  $100 \div 0.83 = 120.5$  kg butter.

If each dairy receives 200 kg of milk per day for 350 days in the year at an average fat content of 4% then the quantity of butterfat received by each dairy is:

 $350 \ge 200 \ge 4 \div 100 = 2800$  kg butterfat

From this quantity of butterfat:

Dairy A makes  $2800 \div 100 \text{ x } 125 = 3500 \text{ kg}$  butter and

Dairy B makes  $2800 \div 100 \text{ x } 120.5 = 3374 \text{ kg}$  butter i.e. a difference of 126 kg butter.

At EB 25 or US\$ 4 per kg this represents a loss of US\$ 504 per annum.

7. Useful formulae for rough estimations

Cream yield of milk,  $\% = \frac{\% \text{ fat in milk} \times 100}{\% \text{ fat in cream obtained}}$ 

Fat % in cream = 
$$\frac{(\% \text{ fat in milk} - 0.03) \times \text{weight of milk}}{\text{weight of cream obtained}}$$

Kg of separated milk obtained in separation = kg of whole milk separated - kg of cream obtained

Kg of buttermilk obtained in churning = kg cream - kg butterfat in cream

Butter yield of milk = 
$$\frac{\text{kg milk x (\% F in milk - 0.05) 1.20}}{100}$$

Butter yield of cream = kg cream x (% F in cream - 0.3) x 1.2

Cheese (Cheddar) yield of average milk = kg fat in milk x 2.7.

### Other calculations

While the calculation of buttermaking efficiency and economic value given in the text provides a useful rule of thumb, the method given below provides a more comprehensive analysis.

To go through this process, the composition of butter must be known accurately. This manual gives the methods for measuring moisture and salt content. Alternatively, the salt content can be calculated, as the amount of salt added is known.

% salt =  $\frac{\text{Grams of salt added}}{\text{Final weight of butter + salt}} \ge 100$ 

The milk SNF content can be assumed to be 0.7%.

Assume that 100 kg of milk containing 4% fat is to be made into butter and that the composition of the butter will be 16% water, 0.7% SNF, 2.0% salt and 81.3% fat.

#### Separation efficiency

Some fat will remain in the skim milk. This should be measured using the Gerber skim milk test. Assume that the fat content of the skim milk is 0.1% and that the fat content of the cream is 35%.

M = weight of milk	Fm = fat content of milk
C = weight of cream	Fc = fat content of cream
S = weight of skim milk	Fs = fat content of skim milk
S + C = M	
or $S + C = 100$	
$\frac{\mathbf{S} \times \mathbf{Fs}}{100} + \frac{\mathbf{C} \times \mathbf{Fc}}{100} = \frac{\mathbf{M} \times \mathbf{Fm}}{100}$	
or $0.001 \text{ S} + 0.35 \text{ C} = 4.0$	
0.001  S + 0.001  C = 0.1	

0.349 C = 3.9

$$C = 11.17$$

Therefore, the separation yields 11.17 kg of cream and 88.83 kg of skim milk.

Therefore, fat losses in the skim milk:

$$\frac{88.83 \times 0.1}{100} = 0.0888 \text{ kg}$$
Percentage loss =  $\frac{0.0888 \times 100}{4} = 2.22\%$ 

#### **Churning efficiency**

Some fat will remain in the buttermilk. This will also have to be determined using the Gerber method as for skim milk.

BM = weight of buttermilk

Fbm = per cent fat in buttermilk = 0.5

B = weight of butter (after salting)

Fb = per cent fat in butter = 81.3

BM + B = 11.17

0.005 BM + 0.813 B = 3.9

0.005 BM + 0.005 B = 0.05585

0.808 B = 3.844B = 4.75

The yield is thus 4.75 kg of butter and 6.42 kg of buttermilk.

The loss of fat is 0.032 kg

Percentage loss =  $\frac{0.032 \times 100}{4}$  = 0.8%

The final production figure (making no allowances for losses during production) is 4.75 kg of butter from 4.0 kg of fat.

Therefore, percentage overrun = 18.75%

However, the actual yield of skim milk is 88.83 kg and there is also 6.42 kg of buttermilk, both of which would be valued (approximately) at 33 cents per kilogram.

Therefore the total value of production:

 $\begin{array}{l} 4.75 \ge 25 \\ 95.25 \ge 0.33 \\ \text{Total value} \end{array} = \frac{\text{EB 31.43}}{\text{EB 150.18}} \end{array}$ 

# Appendix II

## **Glossary of terms**

Acid:	synonym for sour, when lactose has been converted into lactic acid by the action of bacteria.		
Acid curd:	curd formed by the action of bacteria or by adding an acid, e.g. lemon juice or vinegar, to milk.		
Albumin:	a water-soluble protein, a component of whey. It coagulates on heating.		
Annatto:	orange-red dye used to colour cheese.		
Bacteriophage:	a virus that relies on a bacterial host for reproduction. Bacteriophages can prevent acid production in cheesemaking by destroying starter culture bacteria.		
Brine:	a solution of salt and water.		
Casein:	major protein of milk. Coagulated by the action of rennet or acids.		
Colostrum:	the first milk secreted after giving birth.		
Colony:	a compact mass of individual cells which has usually resulted from the multiplication of a single cell.		
Disaccharide:	e.g. lactose, maltose. A sugar composed of two monosaccharide units.		
Homogenise:	to break down the fat globules in whole milk and distribute them evenly so that the cream and milk do not separate.		
Hypochlorite:	chemical solution used after cleaning utensils to destroy micro-organisms.		
Lactation:	period during which milk is secreted.		
Lactose:	milk-sugar. The action of bacteria on lactose produces lactic acid.		
Lactic acid fermentation:	The production of lactic acid from lactose by the action of micro-organisms.		
Lipolytic:	the property of splitting up or hydrolysing fat. Lipases are lipolytic enzymes; lipolytic bacteria are those that break down fat.		
Mastitis :	inflammatory condition of the udder.		
Mesophiles:	micro-organisms that have optimum growth temperatures between 25 and $45^{\circ}$ C.		
Organoleptic:	testing the effects of a substance on the senses, especially of taste and smell.		
Pasteurisation:	heating milk to 73°C for 15 seconds and cooling rapidly to less that 10°C.		
Pathogenic bacteria:	bacteria that cause disease or illness.		
Rennet:	extract of rennin in brine.		
Rennin:	enzyme of a digestive juice of mammals that has the property of coagulating milk.		
Polysaccharide:	e.g. starch, cellulose. A complex carbohydrate of high molecular weight composed of many molecules of monosaccharides.		
Proteolytic:	protein splitting. Proteases are proteolytic enzymes; proteolytic bacteria are those that break down proteins.		
Psychrotrophs:	micro-organisms capable of growth at 5°C or below but their optimum growth temperature may be similar to mesophiles, i.e. 25–45°C.		
Starter:	bacterial culture comprising selected strains and species of lactic acid bacteria used to produce the required acid and flavour development during the manufacture of fermented dairy products.		

**Strippings**: the last drawn milk from the udder at each milking.

Thermoduric bacteria: bacteria capable of surviving pasteurisation.

Thermophiles:

Wheying-off:

Whev:

Yeast:

micro-organisms with an optimum growing temperature of 45–75°C.

greenish liquid obtained during cheesemaking.

free whey escaping from a curd as may occur during yoghurt making.

living cell which ferments sugar. It is larger than a bacteria cell.
# **Appendix III**

## Composition of some foods

		Protein	Fat	Carbohydrate	Ash		
	Water (%)	grams per 100 grams edible portion					
Banana	75.7	1.1	0.2	22.2	0.8		
Beef (approx)	55.0	16.0	28.0	0	0.8		
Butter	15.5	0.6	81.0	0.4	2.5		
Butter oil	0.2	0.3	99.5	0	0		
Buttermilk	90.5	3.5	0.5	4.6	0.8		
Cabbage	92.4	1.3	0.2	5.4	0.7		
Carrots	88.2	1.1	0.2	9.7	0.8		
Catfish	78.0	17.6	3.1	0	1.3		
Cheese							
Ayib	76.0	14.0	7.0	2.0	1.0		
Camembert	52.0	17.0	25.0	2.0	4.0		
Cheddar	37.0	25.0	32.0	2.0	4.0		
Chicken	64.0	32.0	3.0	0	1.0		
Cream	61.0	2.0	33.0	3.0	0.6		
Egg	73.7	12.9	11.5	0.9	1.0		
Garlic	61.0	6.0	0.2	31.0	1.5		
Lettuce	94.0	1.3	0.3	3.5	0.9		
Pineapple (raw)	85.3	0.4	0.2	13.7	0.4		
Potato	75.1	2.6	0.1	21.1	0.9		
Whey	93.1	0.9	0.3	5.1	0.6		
Yoghurt	89.0	3.4	1.7	5.2	0.7		

# **Appendix IV**

## Temperature conversion

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

# Appendix V

## Titratable acidity expressed in different ways

Lactic acid (%)	Soxhlet-Henkel (°SH)	Thorner (°T)	Dornic (°D)
0.0900	4	10.0	9.000
0.1350	6	15.0	13.50
0.1575	7	17.5	15.75
0.1800	8	20.0	18.00
0.2025	9	22.5	20.25
0.2250	10	25.0	22.50
0.2475	11	27.5	24.75
0.2700	12	30.0	27.00
0.3150	14	35.0	31.50
0.3600	16	40.0	36.00
0.4050	18	45.0	40.50
0.4500	20	50.0	45.00
0.4950	22	55.0	49.50
0.5400	24	60.0	54.00
0.5625	25	62.5	56.25
0.6075	27	67.5	60.75
0.6300	28	70.0	63.00
0.6750	30	75.0	67.50
0.7200	32	80.0	72.00
0.7425	33	82.5	74.25
0.7875	35	87.5	78.79
0.8100	36	90.0	81.00
0.8550	38	95.0	85.50
0.8775	39	97.5	87.75
0.9225	41	102.5	92.25
0.9450	42	105.0	94.50
0.9900	44	110.0	99.00
1.0125	45	112.5	101.25

# **Appendix VI**

### Volume unit conversions

To convert	То	Multiply by
Millilitres	gallons	0.00022
	fluid ounces	0.03520
Cubic centimetres	cubic inches	0.061
Cubic metres	cubic inches	61.0 x 10 <sup>-3</sup>
	cubic feet	35.3
	gallons	220.0
Litres	cubic feet	0.0350
	cubic inches	61.03
	fluid ounces	35.196
	gallons	0.2199
	pints	1.7598
	quarts	0.8799
Fluid ounces	gallons	0.0063
	millilitres	28.41
Pints	litres	0.568
Cubic feet	cubic inches	1728.0
	gallons	6.481
	litres	28.32
Cubic inches	cubic feet	0.00058
	gallons	0.0036
	litres	0.0164
Gallons	cubic feet	0.160
	cubic inches	277.3
	litres	4.546
	millilitres	4546.0
	cubic metres	0.0046
	ounces	160.0

# **Appendix VII**

## Table of atomic weights\*

Name	Symbol	Atomic weight	Name	Symbol	Atomic weight
Aluminium	Al	26.98	Lead	Pb	207.20
Argon	Ar	39.95	Lithium	Li	6.94
Barium	Ba	137.34	Magnesium	Mg	24.31
Boron	В	10.81	Manganese	Mn	54.94
Bromine	Br	79.91	Mercury	Hg	200.61
Cadmium	Cd	112.40	Nitrogen	Ν	14.007
Calcium	Ca	40.08	Oxygen	0	16.0
Carbon	С	12.011	Phosphorus	Р	30.97
Chlorine	Cl	35.457	Potassium	Κ	39.10
Cobalt	Co	58.93	Selenium	Se	78.96
Copper	Cu	63.54	Silver	Ag	107.88
Fluorine	F	18.998	Sodium	Na	22.99
Hydrogen	Н	1.008	Sulphur	S	32.064
Iodine	Ι	126.904	Zinc	Zn	65.38
Iron	Fe	55.85			

\* based on the atomic mass of C = 12.

# **Appendix VIII**

## Some standard solutions for volumetric analysis

<b>D</b>	Molecular	Equivalent	0.1M g/li	tre0.1N
Reagent	weight	weight	U	
Acetic acid, CH <sub>3</sub> COOH	60.05	60.05	6.005	6.009
Ammonium thiocyanate, NH4SCN	76.12	76.12	7.612	7.612
Calcium carbonate, CaCO <sub>3</sub>	100.09	50.04	10.08	5.004
Citric acid, C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> H <sub>2</sub> O	210.14	70.04	21.014	7.004
Oxalic acid, (COOH)2.2H2O	126.07	63.03	12.606	6.303
Potassium carbonate, K <sub>2</sub> CO <sub>3</sub>	138.21	69.105	13.821	6.91
Potassium chloride, KCl	74.55	74.55	7.455	7.455
Potassium hydrogen phthalate, COOH.C <sub>6</sub> H <sub>4</sub> .COOK	204.23	204.23	20.423	20.423
Potassium hydroxide, KOH	56.11	56.11	5.611	5.611
Potassium iodate, KIO <sub>3</sub>	214.00	35.666	21.400	3.566
Potassium permanganate, KMnO4	158.03	31.608	15.803	3.161
Potassium thiocyanate, KSCN	97.18	97.18	9.718	9.718
Silver nitrate, AgNO <sub>3</sub>	169.87	169.87	16.987	16.987
Sodium bicarbonate, NaHCO3	84.01	84.01	8.401	8.401
Sodium carbonate, Na <sub>2</sub> CO <sub>3</sub>	105.99	52.995	10.599	5.299
Sodium chloride, NaCl	58.44	58.44	5.844	5.844
Sodium hydroxide, NaOH	40.00	40.00	4.00	4.00
Sodium thiosulphate Na <sub>2</sub> S <sub>2</sub> O <sub>3.5</sub> H <sub>2</sub> O	248.17	248.17	24.817	24.817

# Appendix IX

### Approximate strengths of some commercial laboratory reagents

Reagent	Molecular weight	Average per cent by weight	Average density (g/ml)	Moles/ litre	ml of reagent/ litre to give normal solution
Acetic acid	60.05	99.5	1.051	17.4	57.4
Ammonia (NH <sub>3</sub> )	17	28	0.898	14.8	67.6
Hydrochloric acid	36.5	36	1.18	11.6	85.9
Nitric acid	63.02	71	1.42	15.9	62.5
Phosphoric acid	98	88	1.70	14.7	21.8
Sulphuric acid	98.1	95.5	1.84	17.8	27.9

## Appendix X

### Indicators for volumetric analysis

Indicator	Acid colour	Range	Basic colour		Preparation (% w/v)
Bromocresol purple	Y	5.2–6.8	Pu	0.02	in ethanol
Bromophenol red	Y	5.2-7.0	R	0.04	in water
Cresol red	Y	7.2-8.8	R	0.1	in ethanol
Litmus	R	4.5-8.3	В	0.5	in water
Methyl orange	R	3.1–4.4	Y	0.1	in water
Methyl red	R	4.2–6.2	Y	0.1	in ethanol
Methyl violet GB	В	1.5–3.2	V	0.25	in water
Phenolphthalein	С	8.2–10.0	R	1	in ethanol
Phenol red	Y	6.8–8.4	R	0.10	in ethanol

B = blue; Pu = purple; V= violet; C= colourless; R = red; and Y = yellow.

# **Appendix XI**

## Length and area units

Metric (SI)	Imperial
Kilometre (km)	Mile (mi)
Metre (m)	Yard (yd)
Centimetre (cm)	Foot (ft)
Millimetre (mm)	Inch (in)
1  metre = 1	00 cm= 1000 mm
1 kilometre	e = 1000  m
1 metre $= 3$	39.4 in = 3.28 ft = 1.09 yd
1 yard = $3$	ft = 36 in
1  mile = 52	280 ft = 1760 yd

To convert	То	Multiply by
Inches	Centimetres	2.54
Feet	Metres	0.3048
Yards	Metres	0.9144
Miles	Metres	1609.00
Centimetres	Inches	0.3940
Metres	Feet	3.2810
Metres	Yards	1.0936
Kilometres	Miles	0.6213
Square inches	Square centimetres	6.452
Square feet	Square metres	0.0929
Square yards	Square metres	0.836
Square centimetres	Square inches	0.155
Square metres	Square feet	10.764
Square metres	Square yards	1.197

## **Appendix XII**

### The improved traditional churn for buttermaking

Making the ILCA improved traditional churn

Figure 37 shows the "improved traditional churn" ready for churning. Figures 38 and 39 show the components of the improved churn and the internal agitating system.

Figure 37. Improved traditional churn.





Figure 39. Components of the internal agitator.



### Key to the figures

#### A. Wooden stopper

This fits into the mouth of the clay pot. It holds the internal agitator in position and prevents spillage of milk during churning.

#### B. Clay pot

The body of the churn is a clay pot or gourd. The size of the container will vary with the amount of milk available, but generally should have a total capacity of at least 12 to 15 litres. For churning, however, the container should not be more than half full.

#### C. Padded pot seat

This may be made of cloth or woven hay or straw. It reduces the risk of damage to the clay pot.

#### D. Wooden pole and pegs

The supporting pole is made from one piece of wood and is about 1.5 m long and 55 mm in diameter. The base of the pole is fixed rigidly by sinking it about 40 cm into the ground. Several holes are bored through the upper part of the pole about 3 cm apart; these are used for mounting the braces that connect the supporting pole to the shaft of the agitator.

#### E. Wooden brace

Two wooden braces are used to connect the supporting pole (D) to the shaft of the internal agitator. These braces are flat pieces of wood, about 42 cm long, 10 cm wide and 15 mm thick.

The braces should be placed about 20 cm apart on the supporting pole and locked in place with wooden pegs inserted through the holes in the supporting pole. If you need greater rigidity, use four wooden pegs, one on either side of each brace.

#### F. Internal agitator with paddle blades

This consists of three main components: the shaft and two paddle blades. The shaft of the agitator is made from one piece of wood about 34 mm in diameter and 70 cm long. The paddle blades, each about 13.5 cm long, mount in a slot in the base of the shaft. The paddle blades are kept in position by a wooden plug (dowel). When the agitator is not in use the paddle blades hang vertically, enabling the agitator to be placed in the clay pot.

#### G. Rope and handles

The rope, about 1.6 m long, is passed through a hole in the upper part of the agitator shaft. About half the rope is wound around the shaft and the ends of the rope are tied to wooden handles. Pulling on the handles turns the shaft of the agitator. As the shaft turns, the paddle blades rise to their horizontal, working position.

## Appendix XIII

### Useful references, names and addresses

### References

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### Names and addresses

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