ILCA Manual No. 4

Rural dairy technology

Experiences in Ethiopia

Frank O'Mahony



International Livestock Centre for Africa

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Frank O'Mahony

Dairy Technology Unit
International Livestock Centre for Africa
P.O.Box 5689
Addis Ababa, Ethiopia

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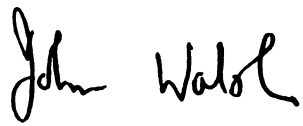
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FOREWORD

The information in this manual is based on ILCA's experiences, and particularly the work of the late Frank O'Mahony, in Ethiopia between 1984 and 1986.

The manual is intended as a teaching aid for extension-level technicians, and this is reflected in the practical nature of the material. The level of technology is largely aimed at individual smallholders, but with some reference to techniques that could be used by groups of farmers or producers' cooperatives.

Despite being limited to experience gained in Ethiopia, we believe that the information and techniques given in this manual will be useful to dairy technologists and development workers in other parts of Africa.



John Walsh
Director General

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1. INTRODUCTION

Milk and milk products have been used by man since prehistoric times. Butter-making was recorded as far back as 2000 B.C. It is thought that cheese-making was discovered accidentally and initially developed in Iraq circa 6000–7000 B.C. and spread with the migration of populations due to famines, conflicts and invasions. Examples of this are the development of Swiss cheeses by the Helveti tribe in Switzerland and the introduction of cheese-making into England by the Romans. Because of the different agricultural conditions prevailing in each country, cheese varieties peculiar to each region developed. 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 produces an acidic product which does not putrefy. Fermented milks are wholesome and readily digestible. Examples of such products are yoghurt, *kefir, koomiss* and acidophilus milk.

The development of the milk separator in the 19th century made centralised milk processing possible. Initially, cream was separated and the fresh skim milk returned to the milk producers, the cream being retained for butter-making. As the nutritional importance of skim milk became recognised, processes were developed to conserve milk solids-not-fat (SNF). Casein and casein products were prepared, as well as lactose and dried milk. Today, a large amount 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 or consumed as fermented milk and products such as butter, ghee and cheese. Sour milk is the most common product, and milk is usually soured before any further processing is done. While there are several milk processing plants in Africa, much of the milk produced by rural smallholders is processed on-farm using traditional technology. It is important, therefore, to consider these processes and look to possible technological interventions at this scale when considering dairy development in the rural sector.

Farmers in the Ethiopian highlands produce sour milk, butter and cottage cheese for sale, and similar products are made in the rangelands. 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; for example, fermented milk can be stored for about 20 days. Milk products are more stable than fresh milk because they are more acidic and/or contain less moisture. Preservatives may also be added. Thus, by increasing acidity and reducing moisture content, the storage stability of milk can be increased.

This manual deals with rural milk processing. It concentrates on Ethiopian traditional products or on products that are easily made, need little specialised equipment and can be easily adapted to the rural processing plant.

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Some background information in the areas of milk chemistry and microbiology is also given. Milk analysis is covered at a simple level, as is dairy engineering, including suitable construction methods and the installation and care of processing equipment.

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2. MILK AS A FOOD

Milk is secreted by the mammary gland of mammals to feed their offspring. Cows milk is commonly used as human food, but milk from sheep, goats, buffalo, yak, horses and camels is also used. Milk contains large amounts of essential nutrients and has rightly been recognised as nature's single most complete food.

As a food, milk serves the following broad purposes: (a) growth, (b) reproduction, (c) supply of energy, (d) maintenance and repair 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 no longer require food for growth whereas infants do. The functions of a food are served specifically through the various nutritionally important components, comprising proteins, carbohydrates, lipids, minerals, vitamins and water.

Nutritionally, milk has been defined as "the most nearly perfect food". It provides more essential nutrients in significant amounts than any other single food. Milk is an outstanding source of calcium and phosphorus for bones and teeth, and contains riboflavin, vitamins B_6, A and B_1 in significant amounts. It also contains B_{12}, the antipernicious anaemia vitamin.

Milk fat or butterfat is the second largest component of milk and is of major commercial value. It serves nutritionally as an energy source and supplies essential fatty acids.

Fat content is closely followed by milk proteins at about 3.4%. Milk proteins in turn are subdivided into casein, comprising approximately 76–80% of the total milk proteins, and the whey proteins, comprising roughly 20–24%. The whey proteins are of higher nutritional value than casein. Milk proteins are outstanding sources of essential amino acids.

The nutritive value of milk products is based on the high nutritive value of milk as modified by processing. Over-processing and, in particular, severe heat treatment reduce the nutritional value of milk. Butter-making concentrates the fat-soluble nutrients, while cheese-making concentrates the milk fat and the major protein fractions.

In some instances milk is fortified with certain nutrients, e.g. vitamin D. It is also possible to replace butterfat with a cheaper fat, as is often done in the manufacture of calf milk replacers and in powdered milk for certain markets. Milk components are also used in other foods: sodium caseinate is used as a protein source in sausages and "filled" meats, whey proteins are used in confectionery and milk proteins are used in sauces for instant foods.

Figure 1 shows the major milk constituents and the products that can be made from each of them. Rural producers make butter and ghee from the fat fraction of milk. Ghee has an excellent storage stability. Where ghee is not made, butter is occasionally spiced and heated to preserve it. Salt is rarely used as a butter preservative in the rural sector.

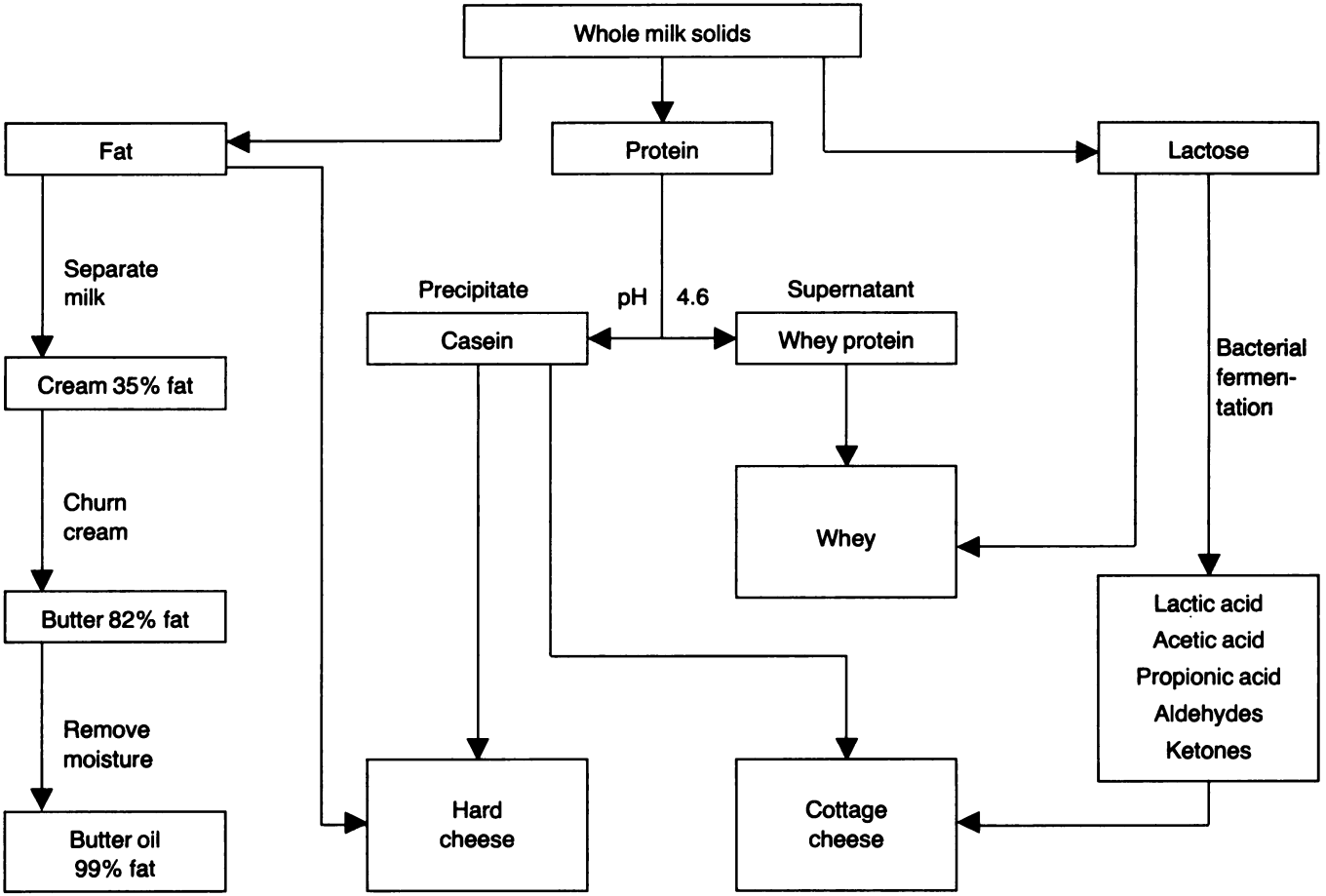
Casein is recovered with fat in cheese-making and can be recovered from sour milk after churning to make a cottage cheese. Because of their greater solubility, the whey proteins are more difficult to recover as a discrete product and in the smallholder setting are best utilised by direct consumption.

Milk sugar — lactose — is soluble in milk. Some people are allergic to fresh milk because of lactose intolerance but

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can consume sour milk because the lactose level has been reduced by fermentation to lactic and other acids. This reduces milk pH and assists in the preservation of other milk solids. Lactic acid contributes to the flavour of many milk products. Because it is present in solution, lactose is difficult to recover as a discrete product.

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



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3. FACTORS AFFECTING MILK COMPOSITION

Milk composition is affected by genetic and environmental factors.

3.1 GENETIC

3.1.1 Breed and individual cow

Milk composition varies considerably among breeds of dairy cattle: Jersey and Guernsey breeds give milk of higher fat and protein content than Shorthorns and Friesians. Zebu cows can give milk containing up to 7% fat.

3.1.2 Variability among cows within a breed

The potential fat content of milk from an individual cow is determined genetically, as are protein and lactose levels. Thus, selective breeding can be used to upgrade milk quality. Heredity also determines the potential milk production of the animal. However, environment and various physiological factors greatly influence the amount and composition of milk that is actually produced. Herd recording of total milk yields and fat and SNF percentages will indicate the most productive cows, and replacement stock should be bred from these.

3.2 ENVIRONMENTAL

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 the morning and evening milking than between the 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 varies little even if the intervals between milkings vary.

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 2 to 3 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 variation in milk constituents throughout lactation is shown in Figure 2.

3.2.3 Age

As cows grow older the fat content of their milk decreases by about 0.02 percentage units per lactation. The fall in SNF content is much greater.

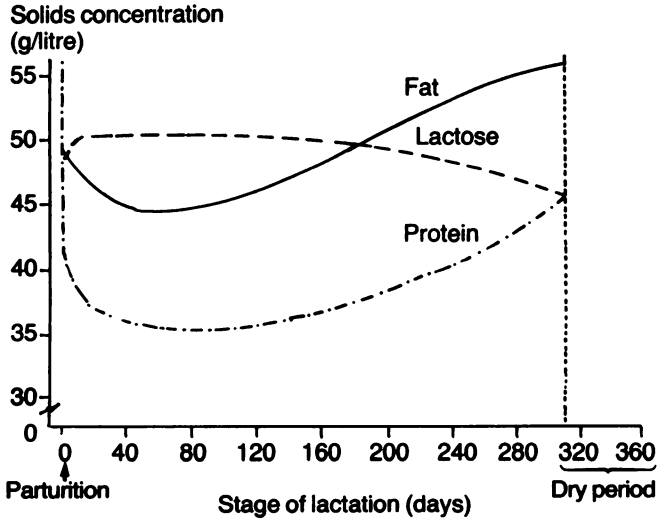
3.2.4 Feeding regime

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

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

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Figure 2. *Changes in the concentrations of fat, protein and lactose over a lactation of a cow.*



3.2.5 Disease

Both fat and SNF contents can be reduced by disease, particularly mastitis.

3.2.6 Completeness of milking

The first milk drawn from the udder is low in fat while the last milk (or strippings) is always quite high in fat. Thus it is essential to mix thoroughly 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.

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4. MILK CHEMISTRY — AN INTRODUCTION

4.1 PHYSICAL STATUS OF MILK

About 87% of milk is water, in which the other constituents are distributed in various forms. We distinguish among several kinds of distribution 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 we find examples of emulsions, colloids, molecular and ionic solutions.

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 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 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 the presence of a surface-active or emulsifying agent 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. In summary, an emulsion consists of three elements, the continuous phase, the disperse phase and the emulsifying agent.

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

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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.

Neutrality is pH 7
Acidity is less than pH 7
Alkalinity is more than 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 a 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 cows milk has a pH of between 6.7 and 6.5. Values higher than 6.7 denote mastitic milk and values below pH 6.5 denote 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 activity; pH measurements are often used as acceptance tests for milk.

Measuring milk acidity is an important test used to determine milk quality. Acidity measurements are also used to monitor processes such as cheese-making and yoghurt-making. The titratable acidity of fresh milk is expressed in terms of percentage lactic acid, because lactic acid is the principal acid produced by fermentation after milk is drawn from the udder and fresh milk contains only traces of lactic acid. However, due to the buffering capacity of the proteins and milk salts, fresh milk 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 cows milk is shown in Table 1.

Table 1. *Composition of cows 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

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

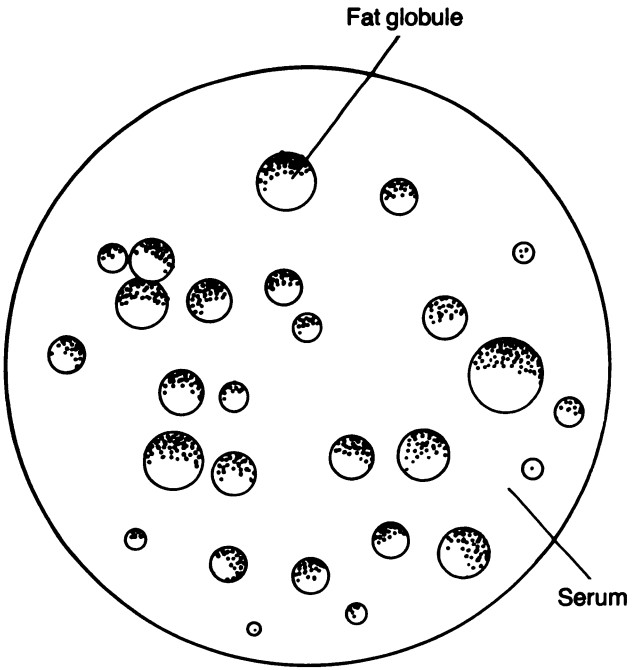
4.3.1 Milk fat

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.

Under the microscope cream can be seen to consist of a large number of spheres of varying sizes floating in the milk. Each sphere 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: this emulsion can be broken by mechanical action such as shaking.

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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.

About 98% of milk fat is a mixture of triacyl glycerides. There are also neutral lipids, fat-soluble vitamins and pigments (e.g. carotene, which gives butter its yellow colour), sterols and waxes. Fats supply the body with a concentrated source of energy: oxidation of fat in the body yields 9 calories/g. Milk fat acts as a solvent for the fat-soluble vitamins A, D, E and K and also supplies essential fatty acids (linoleic, linolenic and arachidonic).

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. In unsaturated fatty acids there is one double bond and in poly-unsaturated fatty acids there is more than one double bond. Examples of each type of fatty acid are shown in Figure 4.

Fatty acids vary in chain length from 4 carbon atoms, as in butyric acid (found only in butterfat), to 20 carbon atoms, as in arachidonic acid. Nearly all the fatty acids in milk contain an even number of carbon atoms.

Fatty acids can also vary in degree of unsaturation, e.g. C18:0 stearic (saturated), C18:1 oleic (one double bond), C18:2 linoleic (two double bonds), C18:3 linolenic (three double bonds).

The most important fatty acids found in milk triglycerides are shown in Table 2. Fatty acids are esterified with glycerol as follows:

$$\begin{array}{l} H_2{-}C{-}OH \\ \quad | \\ H{-}C{-}OH \\ \quad | \\ H_2{-}C{-}OH \end{array} + \begin{array}{l} HOOC{-}R_1 \\ HOOC{-}R_2 \rightarrow \\ HOOC{-}R_3 \end{array} \quad \begin{array}{l} H_2{-}C{-}OOCR_1 \\ \quad | \\ H{-}C{-}OOCR_2 + 3H_2O \\ \quad | \\ H_2{-}C{-}OOCR_3 \end{array}$$

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, 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 the temperature range of 0–40°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. For example, butter made in a smoked gourd has a smokey flavour.

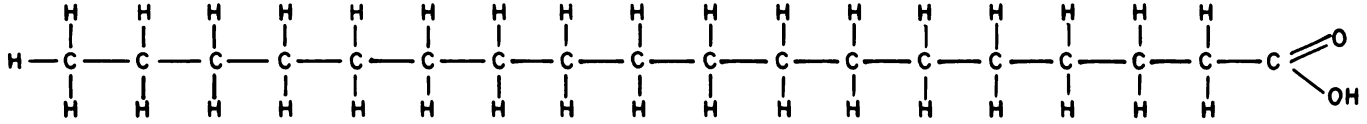
Fats in foods are subject to two types of deterioration that affect the flavour of food products.

1. *Hydrolytic rancidity*: In hydrolytic rancidity, fatty acids are broken off from the glycerol molecule by lipase

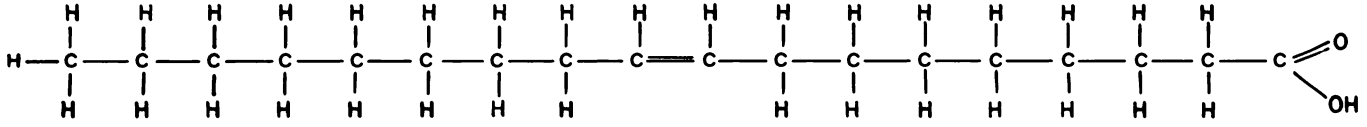
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Figure 4. *Structural formulae of four 18-carbon fatty acids varying in degree of saturation.*

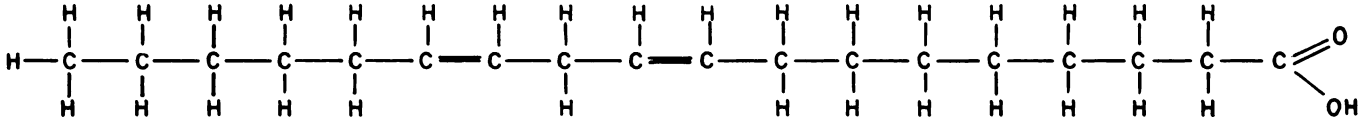
Stearic acid C18:0



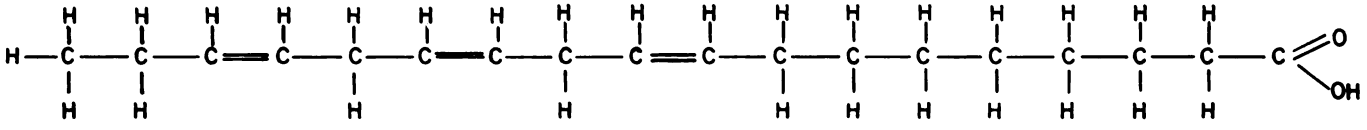
Oleic acid C18:1



Linoleic acid C18:2



Linolenic acid C18:3



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Table 2. *Principal fatty acids found in milk triglycerides.*

	Molecular formula	Chain length	Melting point
Butyric	$CH_3(CH_2)_2COOH$	C_4	−8°C
Caproic	$CH_3(CH_2)_4COOH$	C_6	−2°C
Caprylic	$CH_2(CH_2)_6COOH$	C_8	16°C
Capric	$CH_3(CH_2)_8COOH$	C_{10}	31.5°C
Lauric	$CH_3(CH_2)_{10}COOH$	C_{12}	44°C
Myristic	$CH_3(CH_2)_{12}COOH$	C_{14}	58°C
Palmitic	$CH_3(CH_2)_{14}COOH$	C_{16}	64°C
Stearic	$CH_3(CH_2)_{16}COOH$	C_{18}	70°C
Arichidonic	$CH_3(CH_2)_{18}COOH$	C_{20}	
Oleic	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	$C_{18:1}$	13°C
Linoleic	$CH_3(CH_2)_4(CH{=}CH.CH_2)_2(CH_2)_6COOH$	$C_{18:2}$	−5°C
Linolenic	$CH_3.CH_2(CH{=}CH.CH_2)_3(CH_2)_6COOH$	$C_{18:3}$	

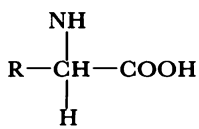
enzymes produced by milk bacteria. The resulting free fatty acids are volatile and contribute significantly to the flavour of the product.

2. *Oxidative rancidity*: Oxidative rancidity occurs when fatty acids are oxidised. In milk products it causes tallowy flavours. Oxidative rancidity of dry butterfat causes off-flavours in recombined milk.

4.3.2 Milk 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 general structure:



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, e.g. lipoproteins contain fat and protein. Such proteins are called conjugated proteins:

Phosphoproteins: Phosphate is linked chemically to these proteins — examples include casein in milk and phosphoproteins in egg yolk.

Lipoproteins: These combinations of lipid and protein are excellent emulsifying agents. Lipoproteins are found in milk and egg yolk.

Chromoproteins: These are proteins with a coloured prosthetic group and include haemoglobin and myoglobin.

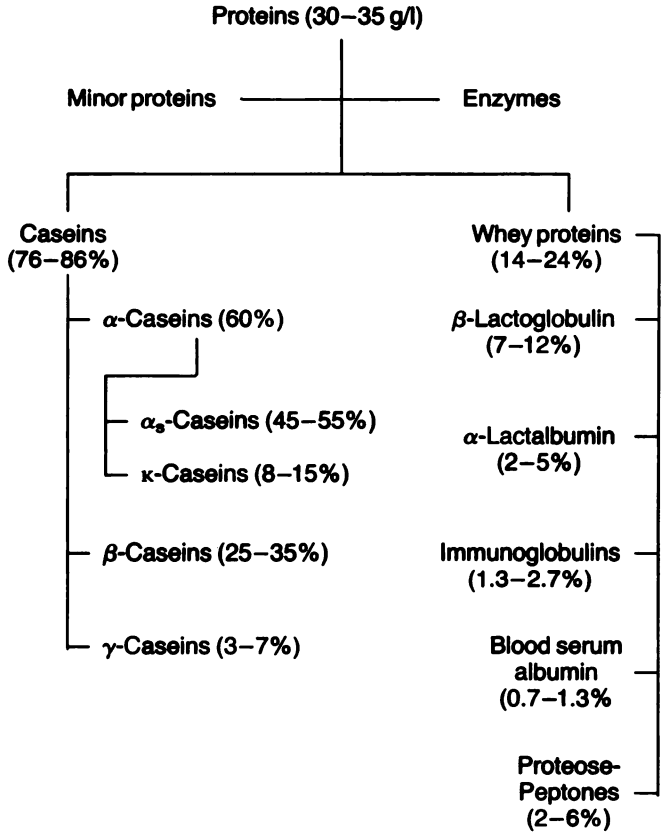
Casein

Casein was first separated from milk in 1830, by adding acid to milk, thus establishing its existence as a distinct protein. In 1895 the whey proteins were separated into globulin and albumin fractions.

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It was subsequently shown that casein is made up of a number of fractions and is therefore heterogeneous. The whey proteins are also made up of a number of distinct proteins as shown in the scheme in Figure 5.

Figure 5. *Milk protein fractions.*



Casein is easily separated from milk, either by acid precipitation or by adding rennin. In cheese-making most of the casein is recovered with the milk fat. Casein can also be recovered from skim milk as a separate product.

Casein is dispersed in milk in the form of micelles. The micelles are stabilised by the κ-casein. Caseins are hydrophobic but κ-casein contains a hydrophilic portion known as the glycomacropeptide and it is this that stabilises the micelles. The structure of the micelles is not fully understood.

When the pH of milk is changed, the acidic or basic groups of the proteins will be neutralised. At the pH at which the positive charge on a protein equals exactly the negative charge, the net total charge of the protein is zero. This pH is called the isoelectric point of the protein (pH 4.6 for casein). If an acid is added to milk, or if acid-producing bacteria are allowed to grow in milk, the pH falls. As the pH falls the charge on casein falls and it precipitates. Hence milk curdles as it sours, or the casein precipitates more completely at low pH.

Whey proteins

After the fat and casein have been removed from milk, one is left with whey, which contains the soluble milk salts, milk sugar and the remainder of the milk proteins. Like the proteins in eggs, whey proteins can be coagulated by heat. When coagulated, they can be recovered with caseins in the manufacture of acid-type cheeses. The whey proteins are made up of a number of distinct proteins, the most important of which are β-lactoglobulin and lactoglobulin. β-lactoglobulin accounts for about 50% of the whey proteins, and has a high content of essential amino acids. It forms a complex with κ-casein when milk is heated to more than 75°C, and this complex affects the functional properties of milk. Denaturation of β-lactoglobulin causes the cooked flavour of heated milk.

Other milk proteins

In addition to the major protein fractions outlined, milk contains a number of enzymes. The main enzymes present are lipases, which cause rancidity, particularly in homogenised milk, and phosphatase enzymes, which catalyse the hydrolysis of organic phosphates. Measuring the inactivation of alkaline phosphatase is a method of testing the effectiveness of pasteurisation of milk.

Peroxidase enzymes, which catalyse the breakdown of hydrogen peroxide to water and oxygen, are also present. Lactoperoxidase can be activated and use is made of this for milk preservation.

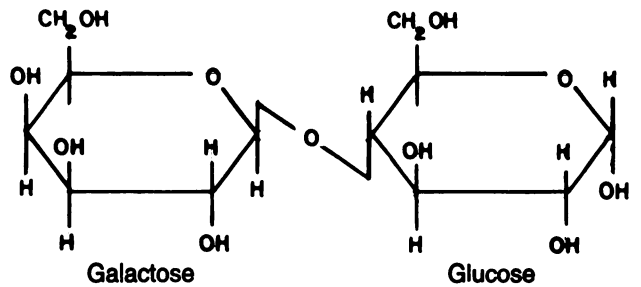
Milk also contains protease enzymes, which catalyse the hydrolysis of proteins, and lactalbumin, bovine serum albumin, the immune globulins and lactoferrin, which protect the young calf against infection.

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4.3.3 Milk carbohydrates

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

Figure 6. *Structure of a lactose molecule.*



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 β-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 cheese-making lactose remains in the whey fraction. 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 used to fortify baby-food formula. 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, and the yeast biomass recovered and used as animal feed. However, these processes are expensive and a large throughput is necessary for them to be profitable. For smallholders, whey is best used as a food without any further processing.

Heating milk to above 100°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.

Some people are unable to metabolise lactose and suffer from an allergy as a result. Pre-treatment of milk with lactase enzyme breaks down the lactose and helps overcome this difficulty.

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

4.3.4 Minor milk constituents

In addition to the major constituents discussed above, 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

Milk salts are mainly chlorides, phosphates and citrates of sodium, calcium and magnesium. Although salts comprise less than 1% of the milk they influence its rate of coagulation and other functional properties. Some salts are present in true solution. The physical state of other salts is not fully understood. Calcium, magnesium, phosphorous and citrate are distributed between the soluble and colloidal phases (Table 3). Their equilibria are altered by heating, cooling and by a change in pH.

Table 3. *Distribution of milk salts between the soluble and colloidal phases.*

	Total	Dissolved	Colloidal
	(mg/100 ml of milk)		
Calcium	1320.1	51.8	80.3
Magnesium	10.8	7.9	2.9
Total phosphorus	95.8	36.3	59.6
Citrate	156.6	141.6	15.0

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In addition to the major salts, milk also contains trace elements. Some elements come to the milk from feeds, but milking utensils and equipment are important sources of such elements as copper, iron, nickel and zinc.

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.

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5. MICROBIOLOGY

Micro-organism is the term applied to all microscopically small living organisms. We tend to associate micro-organisms with disease. Micro-organisms which cause disease are called pathogens. However, few micro-organisms are pathogens and micro-organisms play a crucial part in the life of 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, pathogens — while others are beneficial — cheese and yoghurt starters, yeasts and moulds used in controlled fermentations in milk processing.

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

5.1 BACTERIA

Bacteria are single-celled organisms. They are present in air, water and on most solid materials. Bacterial cells are very small and can only be seen with the aid of a microscope.

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; those that are rod-shaped are called bacilli. This is the first basis for differentiating between bacterial cells.

Bacteria are also classified according to cell cluster formation:

Diplococci – two cocci cells paired
Staphylococci – a number of cells clustered together
Streptococci – a number of cells arranged in a chain

Some bacteria are capable of locomotion by means of flagellae — long, hair-like appendages growing out of the cell. Some rod-shaped bacteria contain spores. These are formed 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 — this gives the cell its shape and retains the constituents;
- Cell membrane — used for filtering in food constituents and discharging waste products;
- Nucleus — where the genetic material of the cell is stored;
- Cytoplasm — a semiliquid proteinaceous substance which contains starch, fat and enzymes.

The cell membrane is semipermeable and allows the cell to feed by osmosis, i.e. the exchange of water between the cytoplasm of a living cell and the surrounding watery material. Only small molecules can pass in and out of the cell, e.g. with a sugar solution on one side of a semipermeable 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.

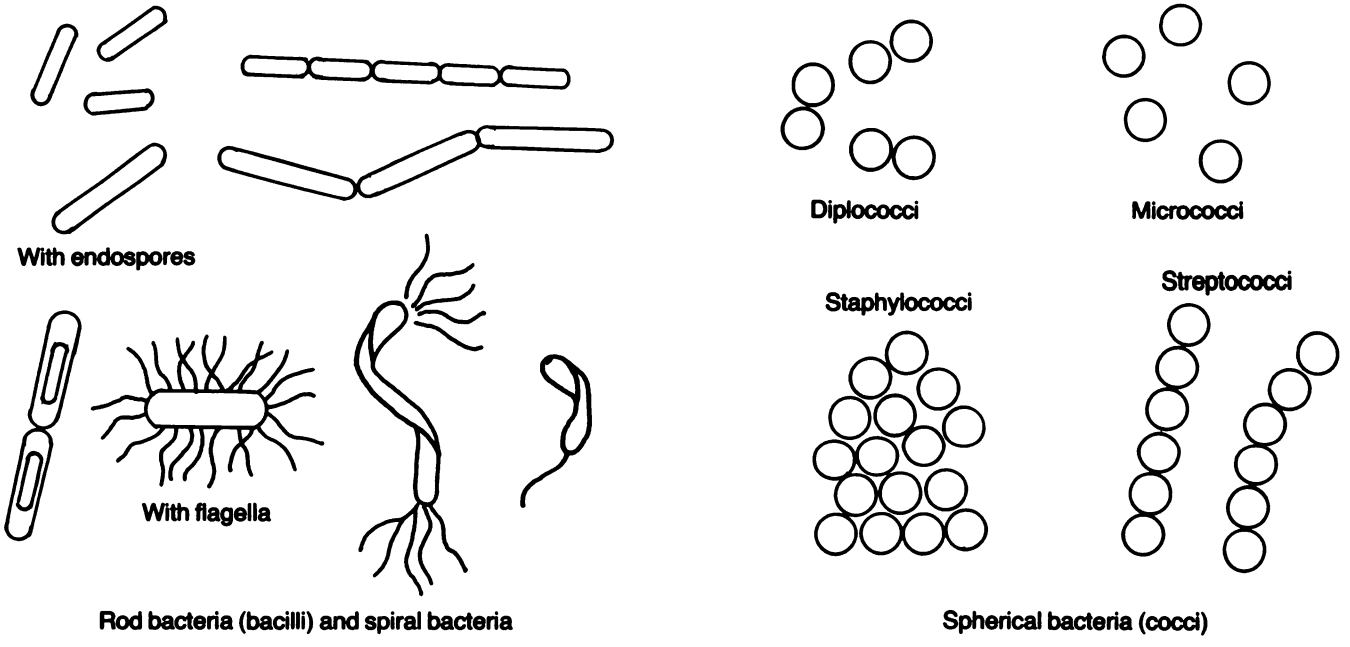
Bacteria can feed by selective intake of nutrients dissolved in water. They can also take in nutrients against the normal osmotic flow — active transport.

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

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



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. The generation time can therefore be defined as the time taken for the cell count to double.

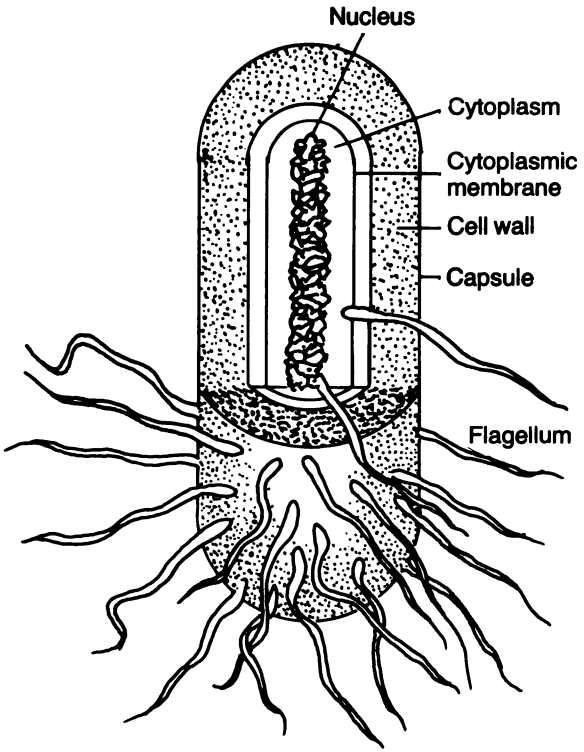
The curve shown in Figure 9 shows the phases of bacterial growth following inoculation of bacteria into a new growth medium. The following phases can be identified:

1. *Lag phase:* There is usually some delay in growth following inoculation of bacteria into a new medium, during which time the bacteria adapt to the medium and synthesise the enzymes needed to break down the substances in the growth medium.
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. A plot of 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.
3. *Stationary phase:* As the bacteria dominate the growth medium, they deplete the available nutrients or 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 cells, resulting in no net change in cell numbers. This phase is called the stationary phase.
4. *Death phase:* In the next phase the formation of new cells ceases and the existing cells gradually die off. This is called the death phase.

The log phase can be prolonged by removing toxic waste, by adding more nutrients or both.

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Figure 8. *Schematic illustration of bacterial structure.*



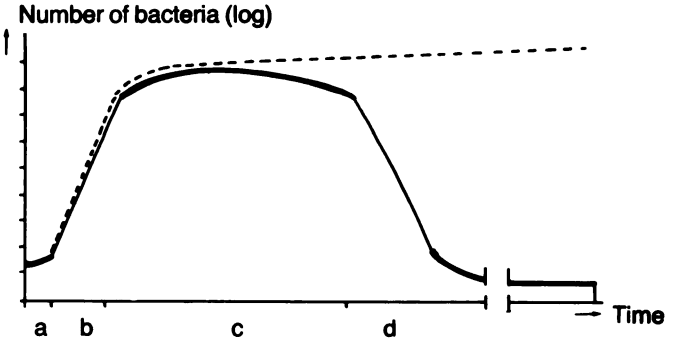
Factors affecting bacterial growth

Bacterial growth is affected by (1) temperature, (2) nutrient availability, (3) water supply, (4) oxygen supply, and (5) 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 in the order of 70°C for 15 seconds, although spore-forming

Figure 9. *The four phases of bacterial growth.*



organisms require more severe heat treatment, e.g. live steam at 120°C for 30 minutes.

Bacteria can be classified according to temperature preference: *Psycrophilic* 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; as well as material for cell formation organic matter also contains the necessary energy. Such 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 whereas others can tolerate dry conditions for months; bacterial spores can

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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.

Bacteria that need oxygen for growth are called *aerobic*. Oxygen is toxic to some bacteria and these are called *anaerobic*. Anaerobic organisms are responsible for both beneficial reactions, such as methane production in biogas plants, and spoilage in canned foods and cheeses.

Some bacteria can live either with or without oxygen and are known as *faculative 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 called *aciduric*. Lactic acid bacteria in milk produce acid and continue to do so until the pH of the milk falls to below 4.6, at which point they gradually die off. In canning citrus fruits, mild heat treatments are sufficient because the low pH of the fruit inhibits the growth of most bacteria.

Bacteria in milk

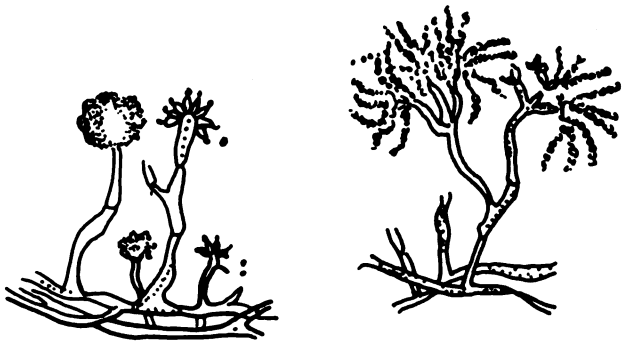
Milk fresh from a healthy cow contains few bacteria, but contamination during handling can rapidly increase bacterial numbers. Milk is an ideal food and many bacteria grow readily in it.

Some bacteria are useful in milk processing, causing milk to sour naturally, leading to products such as *irgo*. However, milk can also carry pathogenic bacteria, such as *Salmonella, Tuberculosis bovis* 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.

Figure 10. *Structure of moulds.*



5.3 YEASTS

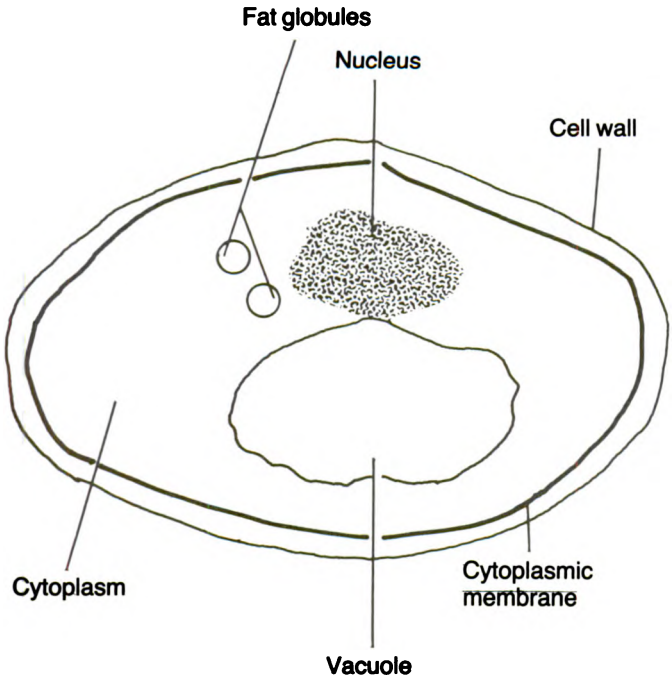
Yeasts are unicellular organisms which reproduce asexually by budding. They are used industrially to ferment carbohydrates to such products as alcohol and citric acid. Yeasts are not usually used in milk processing and are normally regarded as spoilage organisms in dairy products. The structure of yeasts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

5.4 VIRUSES

Viruses are extremely small organisms comprising a spherical head containing the genetic material and a cylindrical tail. They cannot reproduce themselves, and must invade other cells in order to reproduce. Viruses that attack bacterial cells are known as bacteriophages: bacteriophages that attack acid-producing bacteria inhibit acid production in milk.

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Figure 11. *Structure of a yeast cell.*



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 above 16°C.

Microbes can enter milk via the cow, air, feedstuffs, 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. Milking equipment should be washed thoroughly before and after use — rinsing is not enough.

Bacterial types commonly associated with milk are given in Table 4.

Table 4. *Bacterial types commonly associated with milk.*

Pseudomonas	Spoilage
Brucella	Pathogenic
Enterobacteriaceae	Pathogenic and spoilage
Staphylococci	
Staphylococcus aureus	Pathogenic
Streptococcus	
S. agalactiae	Pathogenic
S. thermophilus	Acid fermentation
S. lactis	Acid fermentation
S. lactis-diacetyllactic	Flavour production
S. 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

Microbial growth can be controlled by cooling the milk. Most micro-organisms reproduce slowly in colder environments. Cooling milk also slows chemical deterioration.

The temperature of freshly drawn milk is about 38°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 temperature of the milk will only have fallen to 28°C after 3 hours. Cooling the milk with running water will reduce the temperature to 16°C after 1 hour. At this temperature bacterial growth will be reduced and enzyme activity retarded. Thus, milk will keep longer if cooled.

Natural souring of milk may be advantageous: for example, in smallholder butter-making, 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. The acid-

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ity of the milk also inhibits the growth of pathogens. It does not, however, retard the growth of moulds.

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 consume. 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 reflects directly 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/ml. High counts (more than 10^5/ml) are evidence of poor production hygiene. Rapid tests are available for estimating the bacterial quality of milk.

5.5.1 Milk 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 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 prior to sale as liquid milk. Pasteurisation is used to reduce the microbial counts in milk for cheese-making, and cream is pasteurised prior to tempering for butter-making 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°C and held at this temperature for 30 minutes. The milk is then cooled to 5°C and packed.

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. The major nutrients are not altered. There is some loss of vitamin C and B group vitamins, but this is insignificant.

The process kills many fermentative organisms as well as pathogens. Micro-organisms that survive pasteurisation are putrefactive. Although pasteurised milk has a storage stability of 2 to 3 days, subsequent deterioration is caused by 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 Milk 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 longer shelf life than pasteurised milk.

Another method of sterilisation is ultra-heat treatment, or UHT. In this system, milk is heated under pressure to about 140°C for 4 seconds. The product is virtually 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 extracting and preserving milk fat. It can be made directly from milk or by separation of milk and subsequent churning of the cream.

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5.6.1 Sources of contamination

In addition to bacteria present in the milk other sources of bacteria in butter are (1) equipment, (2) wash water, (3) air contamination, (4) packing materials, and (5) personnel.

Equipment

In smallholder butter-making, bacterial 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. But 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 and butter-working equipment.

Wash water

Wash water can be a source of contamination with both coliform bacteria and bacteria associated with 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 butter-making. 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 to butter via the hands, mouth, nasal passage and clothing. Suitable arrangements for 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. Salt concentration of 2% adequately dispersed in butter of 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. 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 the harmful effects of these organisms.

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6. 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 prior to 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 product.

Because of differences between processing systems, each will be dealt with separately. The section on fresh-milk technology deals with techniques used for processing fresh milk in batches of up to 500 litres. Sour-milk technology is used for processing batches of up to 15 litres of accumulated sour milk. This will be described in the section on sour-milk technology.

6.1 FRESH MILK TECHNOLOGY

This section describes the manufacture of skim milk, cream, butter, butter oil, ghee, boiled-curd and pickled cheese varieties and fermented milks from fresh milk. The processing scale envisaged is 100 to 200 litres of milk per day. However, the processes described are suitable for batches of up to 500 litres per day. Most of the equipment described can be fabricated locally. 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. Importation of such equipment is, therefore, advantageous.

The procedures given here are very precise. In many rural dairy processing plants, however, 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 to the best of one's ability. It is particularly important in cheese-making 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.

6.1.1 Milk separation

The fat fraction separates from the skim milk when milk is allowed to stand for 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.

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:

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

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where r = radius of fat globules
d_1 = density of the liquid phase
d_2 = density of the sphere
g = acceleration due to gravity, and
η = 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_1–d_2: Sedimentation rate increases as the difference between d_1 and d_2 increases. Between 20 and 50°C, milk fat expands faster than the liquid phase on heating. Therefore, the difference between d_1 and d_2 increases with increasing temperature.

g: Acceleration due to gravity is constant. This will be considered when discussing centrifugal separation.

η: 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. These clusters 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.

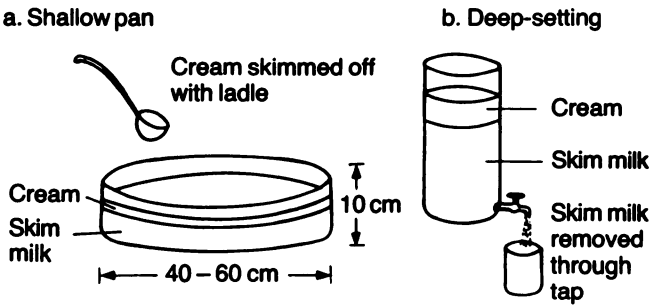
Factors affecting creaming: Cream layer volume is greatest in milk that has high fat content and relatively large fat globules, because such milk contains more large clusters. However, temperature and agitation affect creaming, irrespective of the fat content of the milk. Heating to above 60°C reduces 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 cool place. There are two main methods.

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.

Figure 12. *Batch separation of milk by gravity: (a) Shallow pan method, (b) deep-setting method.*



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).

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.

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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 of different specific gravities, the serum and the fat.

Milk enters the rapidly revolving bowl at the top, the middle or the bottom of the bowl (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.

If we substitute centrifugal acceleration expressed as $r_1\omega^2$ (where r_1 is the radial distance of the particle from the centre of rotation and ω^2 is a measurement of the angular velocity) for acceleration due to gravity (g), we obtain:

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

Thus, sedimentation rate is affected by $r_1\omega^2$. 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.

Efficiency of separation is influenced 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 the separator 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 that affect the skimming efficiency are:

- The quality of the milk: Milk in poor physical condition or which is curdy will not separate completely.
- Maintenance of the separator: A separator in poor mechanical condition will not separate milk efficiently.

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

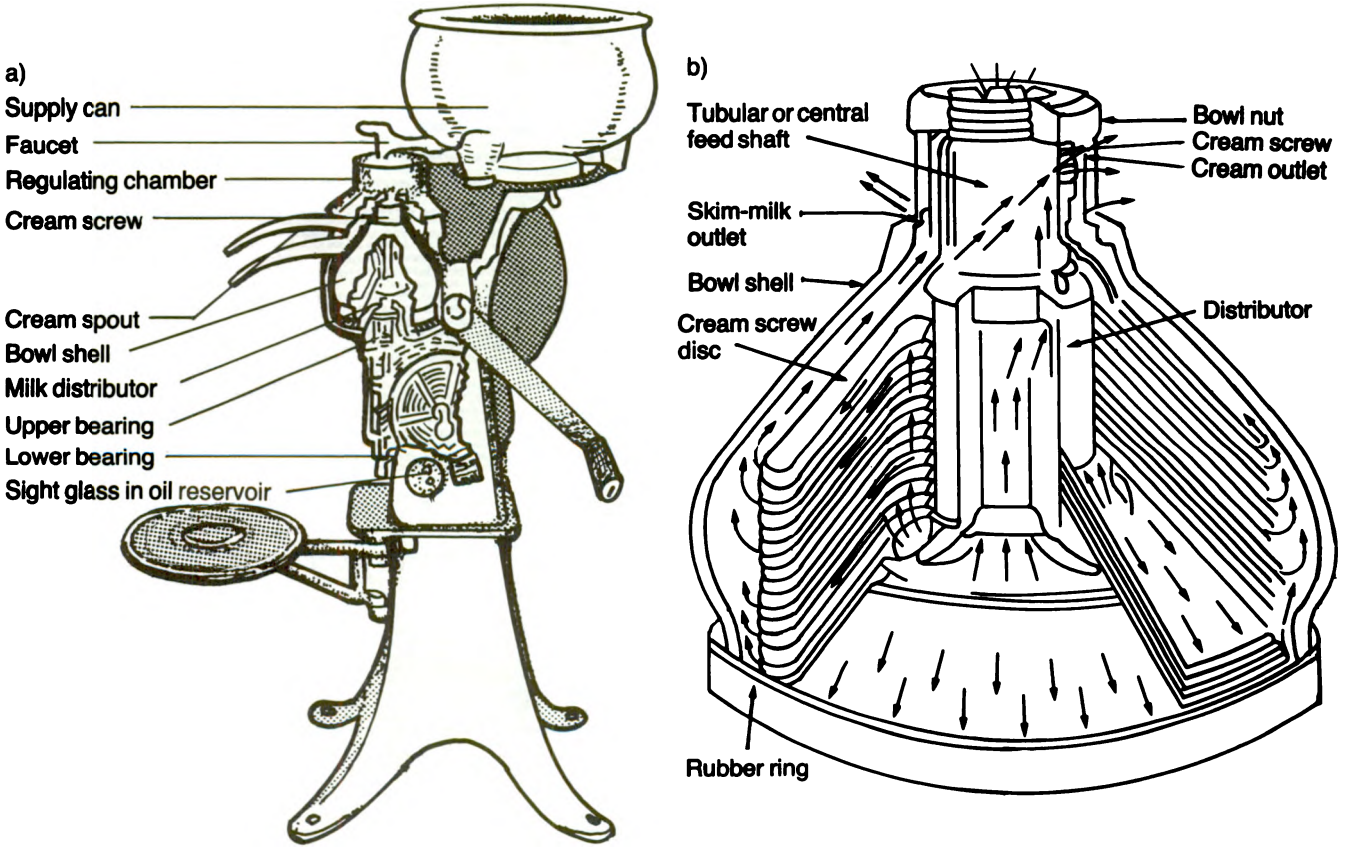
Hand separator

In order to understand how centrifugal separation works, we shall follow the course of milk through a separator bowl. 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.

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



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. Next, 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. Finally, screw the bowl nut on top.

Now the bowl is assembled and ready for use. The rest of the separator is essentially a set of gears so arranged as 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.

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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 the warm water to flow into the bowl. This rinses and heats the bowl and allows a smooth flow of milk and increases separation efficiency.
8. Next, put 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 washed and freed from all impurities the separator bowl becomes a source of microbial contamination. Skimming efficiency is also reduced when the separator bowl and discs are dirty. 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 of the bowl easier. The bowl should then be dismantled. Wash all parts of the bowl, bowl cover, discharge spouts, float supply tank and buckets with a brush, hot water and detergent. Rinse with scalding water. 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 the fat content 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:

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

Wm = weight of milk Fm = fat content of milk

Wc = weight of cream 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 prior to separation to ensure even distribution of cream in the milk.

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.

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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:

$$Wm \times Fm = Wc \times Fc$$

and $Wm - Wc = Ws$

and $Wm - Ws = Wc$

Since $Wm \times Fm = Wc \times Fc$

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

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

$$= Wc$$

In this case: $$Ws = 200 - \frac{200 \times 4.5}{30}$$

$$= 200 - 30$$

$$= 170 \text{ kg}$$

Since $Wc = Wm - Ws$

$Wc = 200 - 170 = 30$ kg

Percentage yield of skim milk:

$$= \frac{Ws \times 100}{Wm} = \frac{170 \times 100}{200} = 85\%$$

Percentage cream (%Wc)

$= \%Wm - \%Ws$

$= 100 - 85 = 15\%$

If in practice we obtain only 28 kg of cream containing 30% butterfat, then (2 x 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:

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

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

If Fm = 3%
Fc = 30%
Wm = 100

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

$$Wc = 100 \times \frac{3}{30} = 10 \text{ kg}$$

$$Ws = Wm - Wc$$
$$= 100 - 10$$
$$= 90 \text{ kg}$$

whereas if Fm = 4%
Fc = 30
Wc = 100

Then $$Wc = 100 \times \frac{4}{30} = 13.3 \text{ kg}$$

$$Ws = 100 - 13.3$$
$$= 86.6 \text{ kg}$$

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

* 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 or if it is consumed directly.

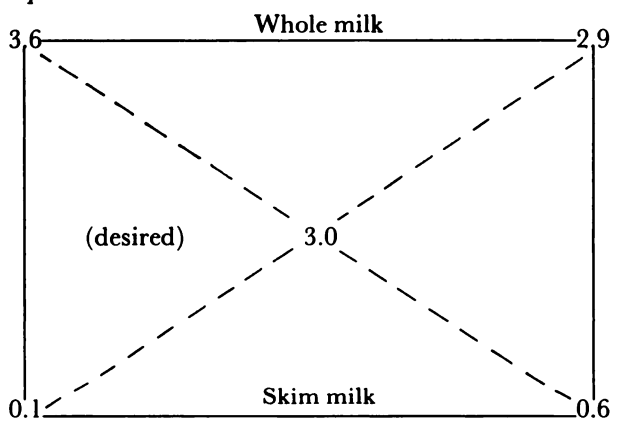
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level, skim milk must be added. This process is known as standardisation.

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.

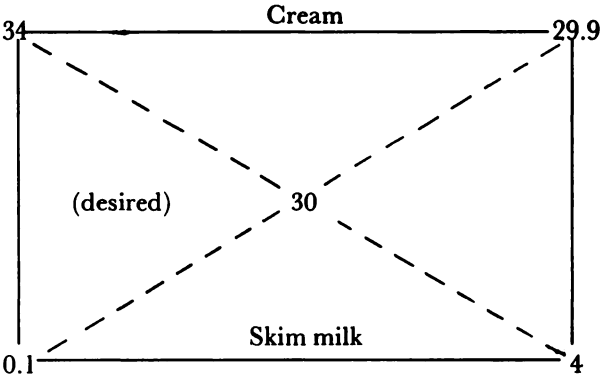
Example 1



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%?

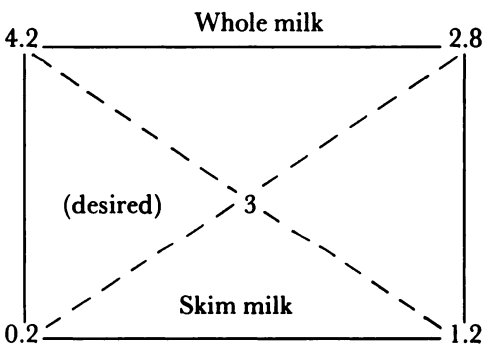


If 29.9 parts of cream require 4 parts of skim milk, 200 parts of cream require x parts of skim milk.

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

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

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

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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% prior to sale as liquid milk but skim milk for standardisation is not available.

In this case, we must calculate (a) what proportion of the milk must be separated to provide enough skim milk to standardise the remaining whole milk and (b) the expected yield of cream.

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 × % fat/100)

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

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.

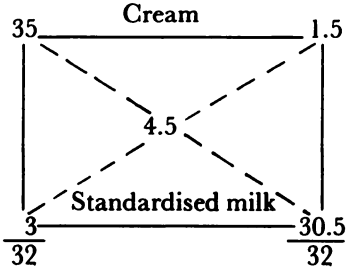
Therefore $4.5 - 1.645 = 2.855$ kg of fat in the standardised milk.

The fat percentage of the standardised milk is

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

The calculation can also be made using Pearson's Square. This is essentially a reverse standardisation, i.e. "how much cream containing 35% fat and milk containing 3% fat should be mixed to get milk containing 4.5% fat?" is mathematically the same as "how much cream containing 35% fat must be removed from milk containing 4.5% fat to standardise the milk to 3% fat content?"

1. Place the fat content of whole milk in the centre.
2. Place the fat content of cream on the top left-hand corner.
3. Place the desired fat content of the standardised milk on the bottom left-hand corner.



4. For every 32 parts of whole milk, there are 1.5 parts of cream to be removed and 30.5 parts of standardised milk.

Therefore $Wc = \frac{1.5}{32} \times 100 = 4.6875 = 4.7$

$Wsm = Wm - Wc = 95.3$

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The Wsm and fat to be removed can be calculated in a number of ways. Whatever method is used to calculate the amount of cream to be removed, it is then necessary to calculate the amount of milk to be separated to achieve the desired reduction in fat content.

$$Wm \times Fm = Wc \times Fc$$

Therefore $Wm \times 4.5 = 4.7 \times 35$

and $$Wm = \frac{4.7 \times 35}{4.5} = 36.5$$

Therefore, 36.5 kg of milk are separated and the skim milk is then combined with the remaining whole milk.

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

Assume liquid milk price of 70 cents/kg

Assume butter price of EB* 10/kg

Income from 100 kg of milk = EB 70

Income from 95.3 kg of milk = 66.71

Fat removed = $Wc \times Fc = 4.7 \times 0.35 = 1.645$

Expected butter yield = 1.9 kg

Income from butter = EB 19

Total income = EB 85.76

Margin = EB 15.76/100 kg of milk

6.1.2 Butter-making with fresh milk or cream

Butterfat can be recovered from milk 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 the butter in tiny droplets. In most dairying countries legislation defines the composition of butter, and butter makers conform to these standards insofar as is possible.

*EB = Ethiopian birr (US$ 1 = EB 2.07)

Butter can be made from either whole milk or cream. However, it is more efficient to make butter from cream than from whole milk.

Butter-making 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. Eventually the fat forms semi-solid butter granules, which rapidly increase in size and separate sharply from the liquid buttermilk. The remainder of the butter-making process consists of removing the buttermilk, kneading the butter granules into a coherent mass and adjusting the water and salt contents to the levels desired.

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 stabilising material from the fat globule surface into the buttermilk;
- The differences in structure between butter and cream; and
- 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 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 de-

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stabilised globules clinging to the air bubbles thus collect in clusters cemented together by free fat. These clusters appear as butter grains.

Churning cream

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

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 a short time. After rinsing again with hot water the churn should be left to air for at least one day before being used.

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 yield of butter 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, or may be 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 as large as small wheat grains.

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 will suffice 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.

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 (refer to method of cleansing and preparing a churn). The butter is spread on the worker, which has been soaked previously with water of the same temperature as the washing water. If salted butter is required, the butter should be salted before working at a rate of 16 g salt/kg or according to taste. 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. If the butter is to be heavily salted, it must be worked more in proportion to the amount of salt used, as uneven distribution of the salt causes 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.

The butter is then weighed and packed for storage. It should be packed in polythene-lined wooden or cardboard cartons and stored in a cool, dry place. The butter should be firm and of uniform colour.

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Washing the churn and butter-making equipment after use

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

Churn: Wash the inside of the churn thoroughly with hot water. Invert the churn with the lid on in order to clean the ventilator; this should be pressed a few times with the back of a scrubbing brush to allow water to pass through. (N.B. 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. This step is very important. Invert and leave to air. Dry the outside and treat steel parts with vaseline to prevent rusting. The rubber band should not be placed in boiling water; dipping in warm water is sufficient.

Butter worker/keeler: Place the sieve, scoop and spades on the butter worker or keeler. Pour hot water over all of them and scrub well to remove all traces of grease. Scald with boiling water and leave to air. Treat the steel part of the butter worker with vaseline to prevent rusting.

Storage of butter

Surplus good-quality butter can be stored, but should contain more salt than usual — at least 30 g/kg. Low moisture content is desirable. 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.

Overrun and produce in butter-making

Overrun

An enterprise engaged in butter-making 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 dairy industry 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.

As stated above, 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, and 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.[1]

Notes:

[1] The need for care when sampling milk is referred to in the section dealing with butterfat testing. 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 x 0.036 = 3.6 kg of butterfat.

Maximum theoretical yield of butter = 3.6 x 1.25 kg = 4.5 kg

Fat received = 100 x 0.032 = 3.2 kg

Maximum theoretical yield = 3.2 x 1.25 = 4 kg

Our overrun therefore is

Butter made = 4 kg

Butterfat paid for = 3.6 kg

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

= 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 in order to trace the loss.

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

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- Losses during separation
- Efficiency of churning.
- The percentage of fat in the butter.[2]
- The amount of salt and water in the butter.[2]
- The amount of product loss throughout the process.

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 for estimating the efficiency of a process is to measure the number of litres of milk required per kilogram of butter produced.

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.

$$\text{In the milk we have 4 kg fat/100 kg or per } \frac{100}{1.032} \text{ litres.}$$

Therefore we have:

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

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 be checked regularly.

[2] 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 legislated for a minimum of 80% butterfat in butter.

Butter quality

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:

- Chemical composition
- Bacteriological composition

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. The butter may also contain pathogens. Cleanliness at all stages of production is, therefore, essential.

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 be 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 the use of preservatives has 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.
- He or she can store the surplus made during the production season for consumption during the season in which he or she cannot produce butter.

The first step the producer can take to ensure a high-quality product is to make it in a clean, hygienic manner.

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This results in fewer spoilage organisms being present in the butter. Another step is to take care in the handling and storage of the butter.

The use of permitted preservatives is by far the most effective means of maintaining butter quality when used in conjunction with the above precautions. Salt — sodium chloride — is an excellent preservative, and salting butter to 3% extends its storage life: salted butter can be stored for up to 4 months without significant deterioration. A salt concentration in excess of 3% gives little advantage and can adversely affect the flavour of the butter.

Aside from the influence of salt on the flavour and keeping quality of the butter, adding salt is of economic importance as it increases overrun.

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.

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.

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.

After salting, the butter should be stored in a clean container, and the container sealed. It should then be stored in a cool, dark place.

Ghee, butter oil and dry butterfat

These products are almost entirely butterfat and contain practically no water or milk 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 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: this 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 prior to 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 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 exhibited excellent keeping qualities over a 5-month test period.

6.1.3 Cheese-making

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.

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 that could be stored as a liquid was the first step towards refining this procedure.

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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 cheese-making.

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:

$$\text{Casein} \xrightarrow[\text{rennet}]{\text{water}} \text{para casein} + \text{glycomacropeptide}$$

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

$$\kappa\text{-casein} \xrightarrow[\text{rennet}]{\text{water}} \underset{\text{(insoluble)}}{\text{para } \kappa\text{-casein}} + \underset{\text{(soluble)}}{\text{glycomacropeptide}}$$

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, during which 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.

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 cows milk, although several varieties are made from the milk of goats, sheep or horses. Flow diagrams for the manufacture of the varieties discussed are shown in Figures 14 to 17.

Queso blanco (White cheese)

Queso blanco is a Latin-American fresh, white cheese. It is usually made from milk containing 3% fat, using an organic acid, without starter or rennet.

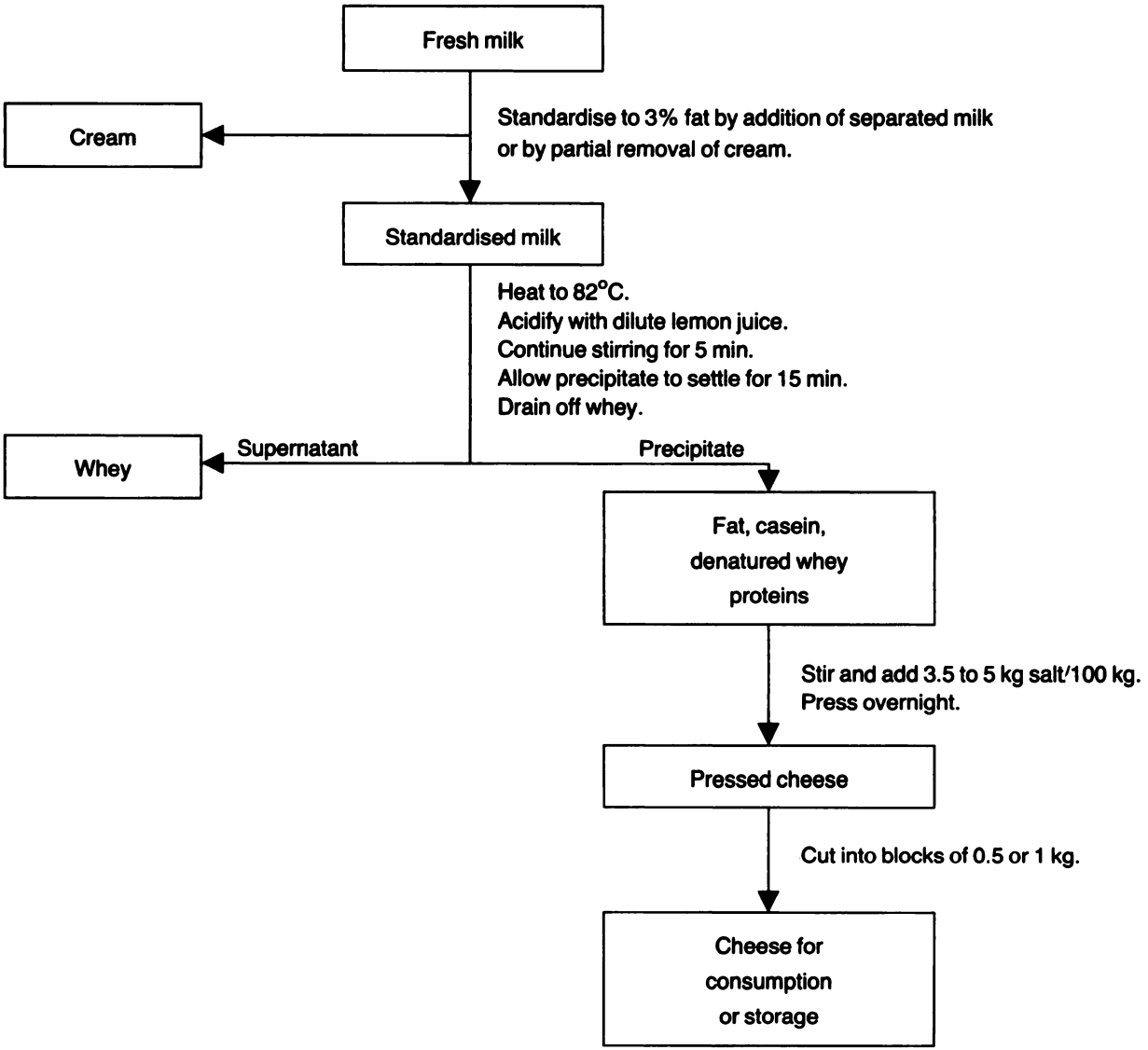
Procedure

1. Take fresh whole milk and determine its fat content. If the fat content is higher than 3%, standardise using skim milk.
2. Transfer the standardised milk to a cheese vat, preferably a double-jacketed standard cheese vat, and heat to 82°C.
3. While the milk is being heated measure out lemon juice of pH about 2.5 in a measuring jar. About 3 ml of lemon juice should be added per 100 ml of milk.
4. Dilute the lemon juice with an equal amount of clean, fresh water.
5. When the milk temperature reaches 82°C, add the diluted lemon juice carefully and uniformly while stirring. For even distribution of the juice, add in three separate amounts.
6. The curd precipitates almost immediately. Continue to stir for 3 minutes after adding the juice, then allow the curd to settle for 15 minutes.
7. Drain the whey through a metal sieve or cheese cloth.
8. While draining the whey, stir the curd to prevent excess matting.
9. Distribute a total of about 3.5 to 5 kg of salt to 100 kg curd, in three applications.
10. Prepare a cylindrical or square hoop by lining with cheese cloth and scoop the salted curds into it.
11. Press the curd overnight at room temperature.
12. Remove the pressed cheese and cut into blocks of 0.5 or 1 kg.

Queso blanco is made without starter or rennet. A variety of acidulants can be used for its manufacture. Heating the milk to 82°C pasteurises the milk and denatures the

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Figure 14. *Manufacturing steps for Queso blanco cheese.*



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whey proteins, so that they are recovered with the curd. This increases cheese yield. The cheese has good keeping quality and is thus suitable for manufacture in rural areas.

Expected yield: 1 kg of cheese from 8 kg of milk (12.5%).

Halloumi

Halloumi is the curd, formed by coagulating whole milk using rennet or similar enzymes, from which part of the moisture (whey) has been removed by cutting (bleeding), warming and pressing.

Procedure

1. Heat the milk to 32–35°C.
2. Add rennet or a similar enzyme according to the manufacturer's directions, while stirring the milk.
3. Hold the milk at 32–35°C until the curd sets.
4. Check for setting of the curd by applying pressure to the edge of the milk where it comes in contact with the vat, using a spatula or a knife with a round tip. If the curd is set it comes away clean from the wall of the vat.
5. After coagulation, the curd is cut into 3–5 mm cubes using vertical and horizontal knives.
6. Hold the curd in whey for about 20 minutes, stirring gently and continuously, and then allow it to settle.
7. Drain the whey and scoop out the curd into a hoop lined with cheese cloth. Press the curd.
8. While the curd is in the press, heat the whey to about 80–90°C. This precipitates the whey proteins, which can then be removed and pressed to make a whey cheese (*anari*).
9. Take out the pressed curd, cut it into pieces of 10 x 10 x 3 cm and heat at about 80°C in hot whey. Continue heating until the pieces of curd float on the surface of the whey and become soft and elastic.
10. Remove the pieces of curd when still warm and either press in the hands, folded or unfolded, and rub in a little dry salt mixed with dried leaves of *Mentha viridis* (spearmint).
11. When the pieces are cold, put them in containers filled with cool, boiled whey brine and store in a cool place to ripen for about 30 days.
12. After ripening put in an airtight container and store in a refrigerator at less than 12°C. The cheese will keep for several months under these conditions. Halloumi cheese is best after 40 days but can also be consumed just after manufacture.

Note: 15% salt concentration in whey brine is normally used.

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

Domiati — Gybna beyda

Known as Domiati in Egypt and Gybna beyda in Sudan, this is a hard, white cheese.

Procedure

1. Heat fresh milk to 35°C and add enough salt to give a 7 to 10% salt solution in the milk.
2. Add enough rennet to coagulate the milk in 4 to 6 hours.
3. Once set, transfer the coagulum to wooden moulds lined with muslin.
4. Allow the whey to drain overnight.
5. On the following day, pack the cheese in tins and fill the interspaces with whey.
6. Seal the tins by soldering.

Notes:

1 and 2. In some areas rennet is added before salting. In this procedure, salt is not added until a coagulum has formed. If salt is added before rennet it is not advisable to add more rennet to shorten the coagulation time, as this reduces the quality of the cheese.

6. Whey expulsion continues during storage and the cheese hardens.

Expected yield: 1 kg of cheese from 7 kg of milk (15%).

Feta

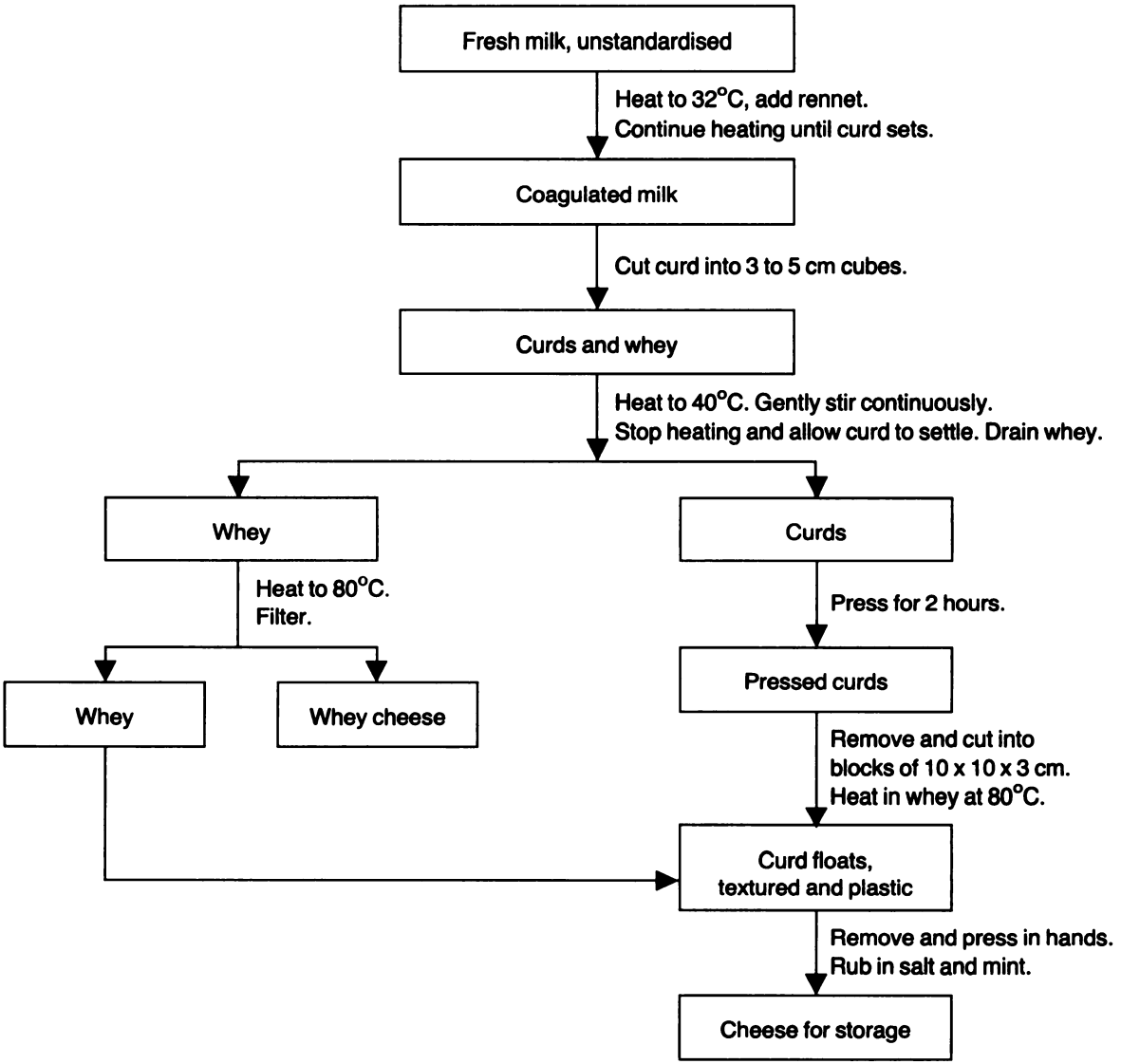
This is a brine-pickled cheese. It can be made from milk of cows, sheep or goats. Feta can be made without starter and can also be made from standardised milk. The procedure described here is for the manufacture of a feta-type cheese without starter or additives.

Procedure

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.

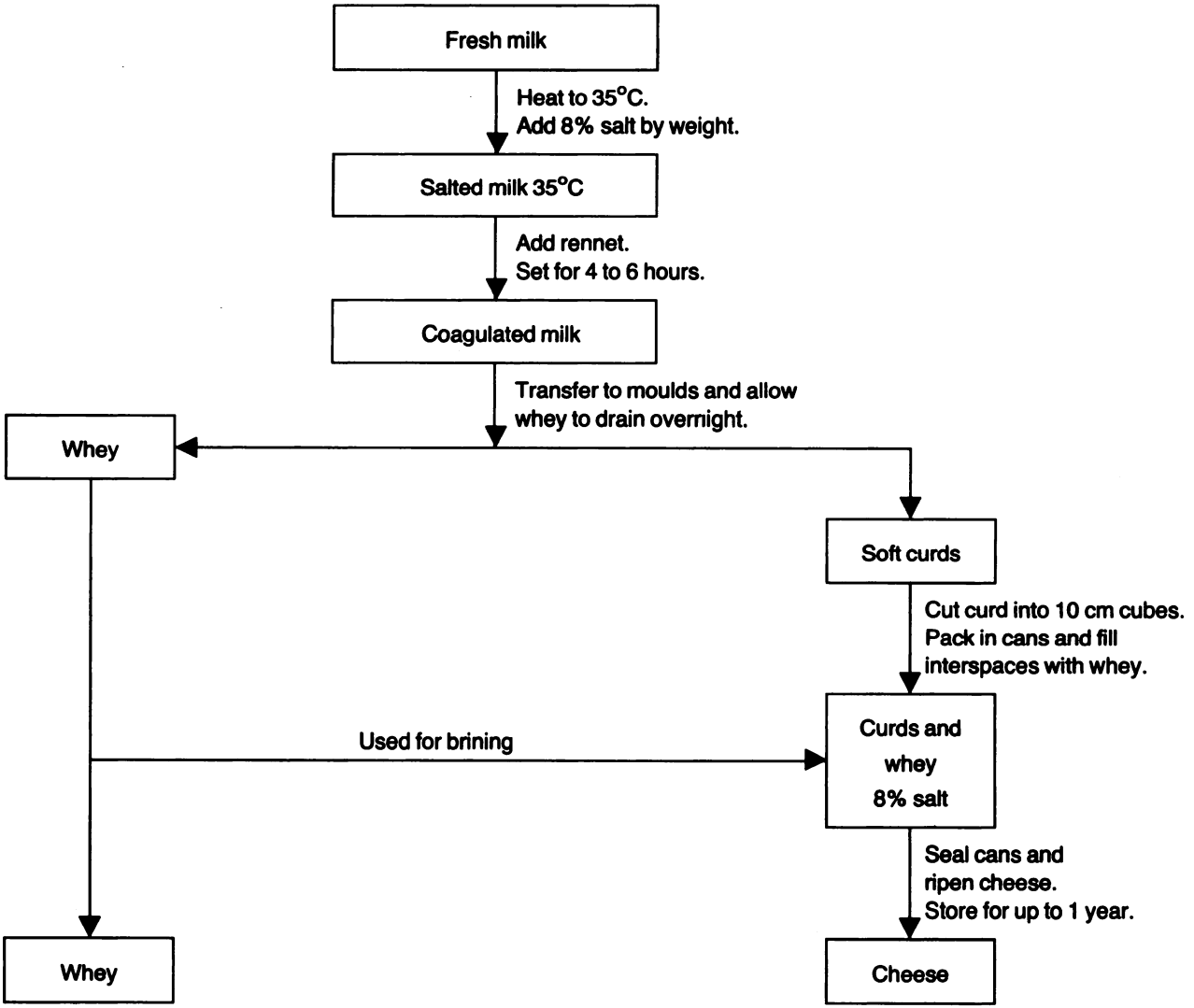
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Figure 15. *Manufacturing steps for Halloumi cheese.*



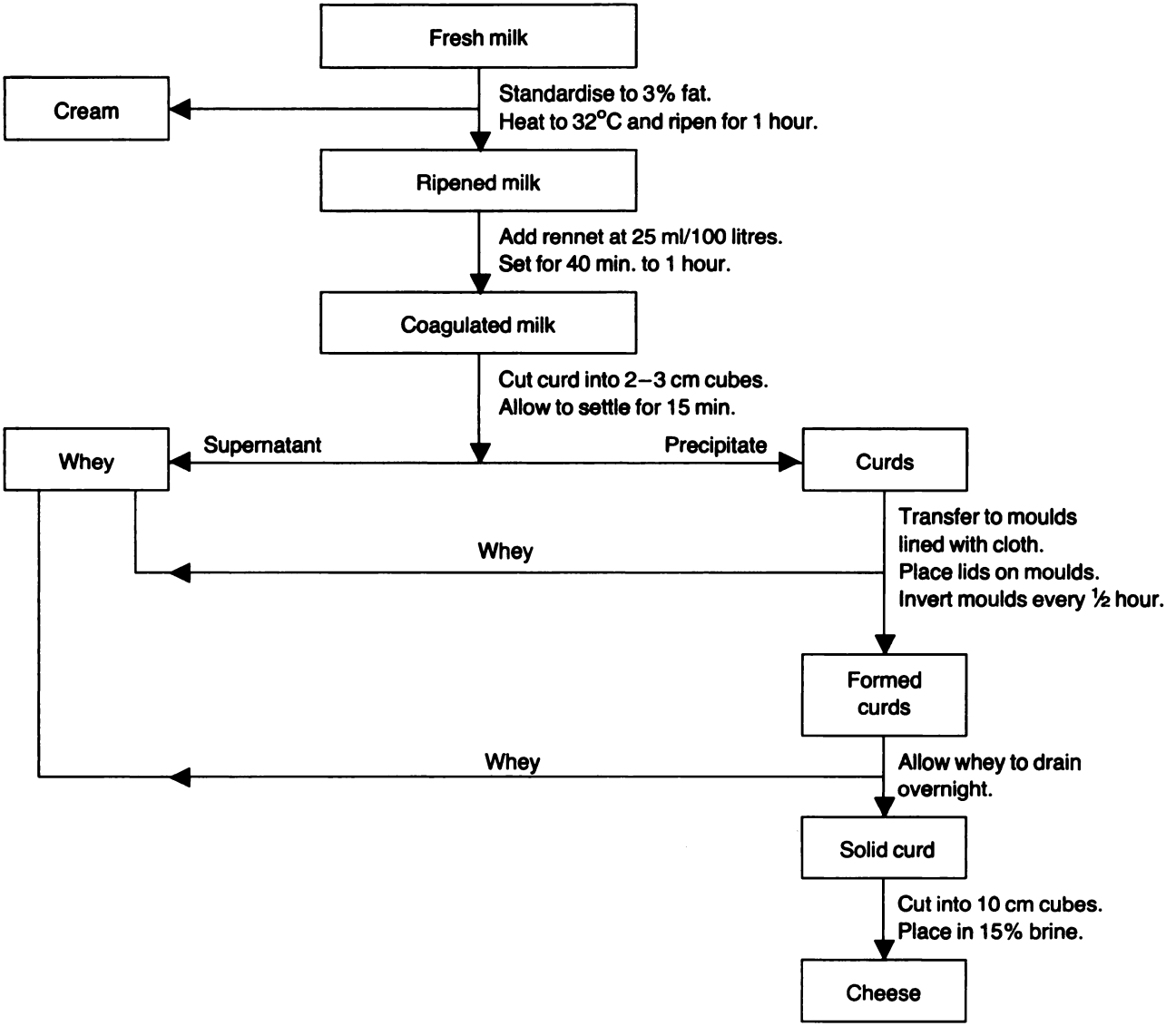
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Figure 16. *Manufacturing steps for Domiati/Gybna beyda cheese.*



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Figure 17. *Manufacturing steps for Feta cheese.*



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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. On the following day, 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.

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

Feta cheese can be eaten after a few days or can be stored for long periods in the brine, provided that air is excluded. The cheese develops a soft, crumbly texture during ripening.

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

Cheese yield

In cheese-making, the milk fat and casein are recovered with some moisture. The yield of cheese can be expressed in kilograms of cheese obtained per 100 kilograms 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 cheese-making.

Milk low in total solids will give a low cheese yield, while milk high in total solids will give a high cheese yield. In order 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 is often used to estimate cheese yield:

$$(2.3 \times \text{fat \%}) + 1.4 = \text{cheese yield (kg/100 kg milk)}$$

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

$$(2.3 \times 4) + 1.4 = 10.6 \text{ kg/100 kg milk}$$

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 yield of cheese 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 cheese-making enterprises, an average annual yield of 9.5%, i.e. 9.5 kg of cheese per 100 kg of milk, is used.

Milk standardisation may be used to increase cheese yield, particularly with high-fat milk. Standardisation also gives a good return for skim milk. However, over-standardising 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 cheese yield. Waxing reduces moisture loss, as does storing the cheese in brine.

6.1.4 Milk fermentations

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. Anaerobic breakdown of carbohydrate to organic acids or alcohols is called fermentation.

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

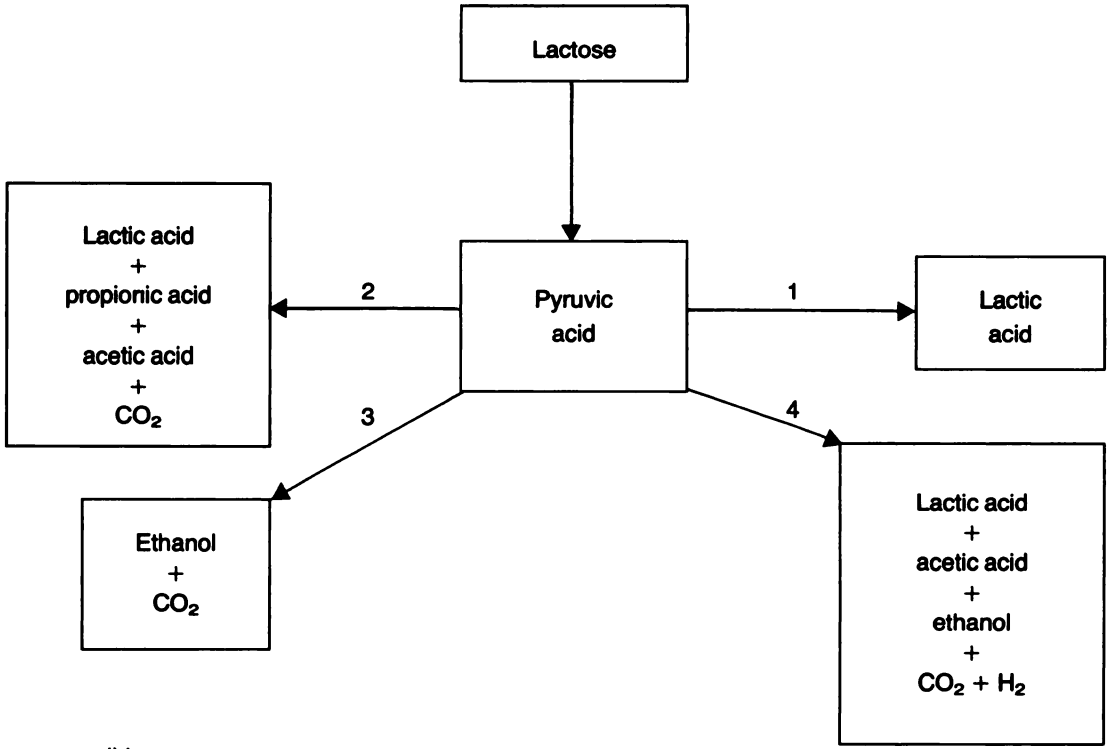
$$C_6H_{12}O_6 \longrightarrow 2\,CH_3.CO.COOH$$

However, fermentations are usually described by an identifiable 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 18.

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Figure 18. *Outline of four important lactose fermentations.*



Organisms responsible:

1. Streptococci and Lactobacilli.
2. Propionibacteria.
3. Yeasts – Candida and Torula.
4. Coliform bacteria.

- 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.
- 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 will generally parallel

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the microbial growth curve up to the stationary phase. The type of fermentation obtained will depend 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, traces of milk from previous batches are often used to provide 'starter' for subsequent batches. Other sources include the container and additives such as cereal grains.

The fermentation will be established once the organisms dominate the medium and will continue 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.

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 19.

Standardisation

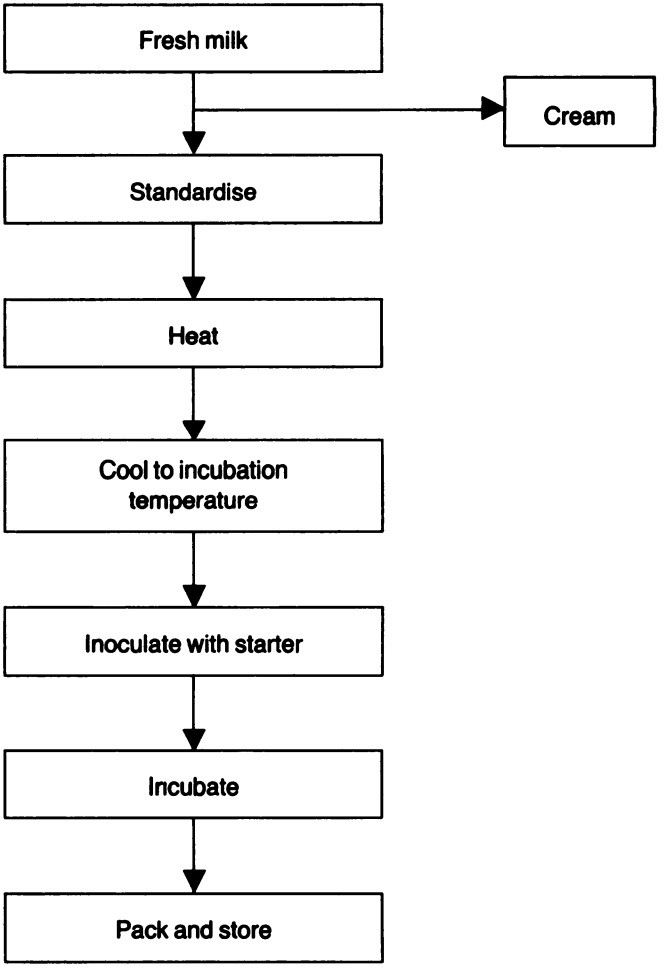
Occasionally some fat is removed or milk SNF added. In some instances, the removal of moisture during heating increases the proportion of solids in the final product.

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.

Figure 19. *Flow diagram of fermented milk manufacture.*



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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 is continued until the fermentation is complete, at which time the product is cooled. Additives may be added at this stage and the product packed.

The manufacturing procedures for a number of fermented milks are given in Table 5.

Preparation of the fermentation vessel

The fermentation vessel is first washed to remove visible dirt. It is then dried and smoked by putting 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 prior to fermentation. It is then allowed to cool and the surface cream removed. In other processes the milk is not given any prefermentation 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 2 days, but may be continued for a further 2 days, by which time the flavour is fully developed. The milk must ferment at low temperature, otherwise fermentation is too vigorous, with much wheying off and gas production.

The product has a storage stability of 15 to 20 days.

Table 5. *Manufacturing procedures for yoghurt, acidophilus milk and kefir.*

Product	Milk	Standardise	Sterilise	Starter	Incubation temperature	Incubation time
Yoghurt	Cows	Optional	95°C 30 min.	*S. thermophilus* *L. bulgarian*	37°C	4–6 hours
Acidophilus milk	Cows	Optional	120°C 20 min.	*L. acidophilus*	38°C	18–24 hours
Kefir	Cows Ewes Goats Mares	—	85°C 30 min.	Kefir grains*	22°C	12 hours

* 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.

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Concentrated fermented milks

Concentrated fermented milks are 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. The milk is allowed to ferment in a cool place for up to 7 days, during which milk may be added daily. After 7 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 actual degree of concentration depends on the amount of whey removed and of fresh milk added.

Milk

Fat, Casein → Coagulum → Stored

Whey proteins → Whey → Fed to calves

6.2 SOUR-MILK TECHNOLOGY

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 made are cheese and products made by mixing fermented milk with boiled cereals.

The equipment required for processing sour milk is simple and is all 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.

6.2.1 Making butter and cottage cheese from sour whole milk

The products and byproducts of butter-making from sour whole milk are shown in Figure 20.

Butter-making from sour whole milk

This is a very important process in many parts of Africa. Smallholders produce 1 to 4 litres of milk per day for processing. Under normal storage conditions the milk becomes sour in 4 to 5 hours. The souring of milk has a number of advantages. It retards the growth of undesirable microorganisms, 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 holds about 20 litres and the amount of milk churned ranges from 4 to 10 litres. The milk is normally accumulated over 2 or more days. 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 from. It can also be agitated by shaking the churn on the lap or hung from a tripod.

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

- Milk acidity
- Churning temperature
- Degree of agitation, and
- Extent of filling the churn

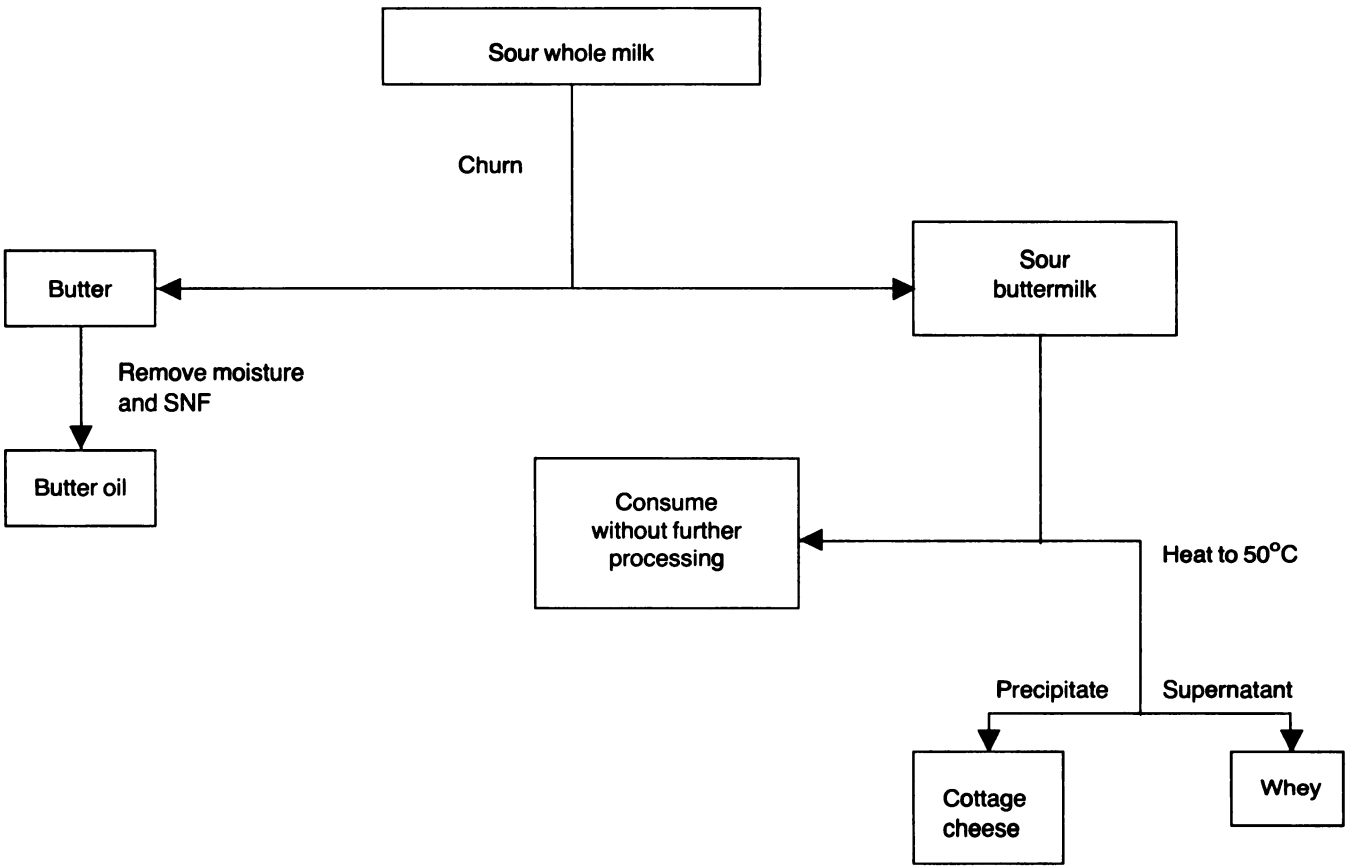
Effect of acidity: Fresh milk is difficult to churn: churning time is long and recovery of butterfat is poor. Milk containing at least 0.6% lactic acid is easier to churn. Acidity higher than 0.6% does not significantly influence churning time or fat recovery.

*Effect of temperature**: Sour milk is normally churned at between 15 and 26°C, depending on environmental temperature. At low temperatures churning time is long; buttergrain formation can take 5 hours or longer. As churning temperature increases churning time decreases. This be-

* It is difficult to isolate the effects of temperature and acidity on churning efficiency because while the milk is ripening it is also cooling and the fat is crystallising. Direct acidification of fresh milk increases butter yield, but allowing milk to develop acidity during a ripening period of 2 to 3 days allows considerable fat crystallisation.

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Figure 20. *Products and byproducts of butter-making from sour whole milk.*



comes marked at temperatures above 20°C, but as little as 60% of the butterfat may be recovered as butter at 26°C. Control of temperature is therefore critical.

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. However, the process is very temperature-dependent and churning at temperatures above 20°C results in short churning times with poor recovery of fat. The optimum churning temperature is between 17 and 19°C.

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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 regulated 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, the soured skim milk contains casein, whey proteins, milk salts, lactic acid, lactose, the unrecovered fat and some fat-globule-membrane constituents.

Defatted milk is suitable, and is often used, for direct consumption. It is also used to inoculate fresh milk to encourage acid development.

Cottage cheese

The casein and some of the unrecovered fat in skim milk 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 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 can be consumed by humans or fed to animals.

The cottage cheese comprises 79.5% water, 14.7% protein, 1.8% fat, 0.9% ash and 3.1% soluble milk constituents. It has a short shelf-life because of its high moisture content. Shelf-life can be increased by adding salt or by reducing the moisture content of the cheese. Storing the product in an air-tight container also extends storage life.

Equipment: 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.

Expected yield: The yield depends on milk composition and on the moisture content of the product, but should be at least 1 kg of cottage cheese from 8 litres of milk (12.5%).

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7. MILK RECEPTION

Milk is brought from the farm to the dairy for processing. When received at the dairy, the following information on the milk is required:

- Quality
- Weight
- Composition
- Presence of contaminants — neutralisers, preservatives etc., and
- Presence of added water.

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.

Weight

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 and a stainless-steel bucket can be used to weigh milk. The milk weight must be recorded accurately as losses can be incurred or underpayments made to suppliers if care is not taken at this stage.

Composition of milk and presence of additives

A dairy engaged in butter-making will need to base its payments on the butterfat content of the milk. The milk received will have to be sampled for butterfat analysis. The procedure for this is dealt with below. Spot checks can also be carried out to test for added water and the presence of neutralisers if malpractice is suspected.

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8. DAIRY ACCOUNTING

To facilitate the recording and accounting of milk supplies each supplier should be given a code number. This code should have two elements:

1. A code for the producer and
2. A code for the dairy cooperative or peasants' association of which the producer is a member; a register of producers and their corresponding codes should be kept at the dairy centre.

The code is recorded in the milk record book, with the weight of milk received, and also on the sample bottle. The supplier should be given a copy of this record each week. He/she should be informed each day of the quality of the milk delivered.

Once the products to be made from the milk have been decided and the prices of the products determined, milk price can be calculated as follows, assuming that butter and cottage cheese are the chosen products*:

1. Calculate the value of 1 kg of butterfat from the known price of butter, e.g. EB 10.
   Butter comprises 80% butterfat. Other constituents are regarded as having no commercial value. Therefore, the price of 1 kg of butterfat

$$= \frac{10 \times 100}{80} = \text{EB } 12.5$$

2. Calculate the value of 1 litre of skim milk.
   Cottage cheese made from fermented skim milk has a value of EB 1.50/kg. Since there is about an 8-fold concentration of casein in the manufacture of cottage cheese from skim milk, assume an average yield of 1 kg of cottage cheese from 8 litres of skim milk. Therefore, each litre of skim milk has a value of 18 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 1.032 kg/litre.
   Therefore, the weight of milk received
   $= 100 \text{ litres} \times 1.032 = 103.2 \text{ kg}$
   Weight of fat received can be calculated by multiplying the weight of milk received by the fat content:
   $= 103.2 \times 0.04 = 4.128 \text{ kg}$
   Value of butterfat purchased from the producer is equal to the weight of butterfat received multiplied by the price per kg of butterfat:
   $= 4.128 \times \text{EB } 12.5 = \text{EB } 51.60$
   3.2. Calculate the volume and value of the skim milk.
   While the actual recovery of skim milk may be greater, in commercial practice it is normally assumed that 80% of the whole milk is recovered as skim milk.
   In this case, we therefore recover 80 litres of skim milk with a value of 18 cents/litre.
   Value of skim milk $= 80 \times 0.18 = \text{EB } 14.40$

* The method given here is a "rule-of-thumb" approach — for further details, see Appendix 1.

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

EB 51.60 for butterfat
EB 14.40 for skim milk

EB 66.00

Therefore, the average value of 1 litre of milk is 66 cents.

It is important to note that, since the butterfat is the most valuable commercial fraction, milk price will vary in proportion to butterfat content.

It is assumed that butterfat content can be estimated. In large dairy plants, milk price is based on the content of the major milk constituents. For small-scale milk processors, this is not normally feasible and payment should be based on fat content.

Production costs and depreciation are deducted proportionally from milk price. Other deductions may also be made when calculating the price paid to the producer for milk.

8.1 MILK ANALYSIS

Milk analysis is carried out to determine:

- Freshness
- Adulteration
- Bacterial content, and
- Milk constituents for payment calculation.

8.1.1 Sampling

A representative sample is essential for accurate testing. 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 prior to 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 small 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 when it is at a temperature between 15 and 32°C. If the cream is too cool it will be thick and viscous and will be 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 to await analysis. Samples of milk or cream for butterfat analysis can be preserved using formalin, corrosive sublimate or potassium dichromate. For general analyses, formalin is preferred, because the other two increase the solids content of the milk, influencing total solids determination.

8.1.2 Estimation of milk pH by 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 on creamery platforms as rejection tests 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.

8.1.3 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 hydronium 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.

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

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Preparation of the pH meter

1. The pH meter should be kept in a dry atmosphere.
2. Before using a new glass electrode, or a glass electrode which has been stored for some time, soak the electrode in N/10 HCl for about 5 hours.
3. Care should be taken not to scratch glass electrodes against the sides of beakers or other hard surfaces during storage or testing.
4. The level of saturated potassium chloride in the calomel electrode should be checked before making pH measurements.
5. Crystals of potassium chloride should be present in the solution within the electrode.
6. The rubber stopper or cap on the filling arm of the calomel electrode should be removed 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 of the meter 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 until the pointer of the meter reads the pH of the buffer.
5. Set the range switch to zero.
6. Before measuring the pH of the test sample, 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 instruction for the particular instrument.

8.1.4 Determination of milk acidity

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 dairy products at any time is a rough indication of the age of the milk and the manner in which it has been handled. As mentioned earlier, fresh milk has an initial acidity due to its buffering capacity.

Apparatus

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

Reagents

- One percent alcoholic solution of phenolphthalein
- N/10 or N/9 sodium hydroxide

i. Using N/10 sodium hydroxide

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, place 18 g in the cup using a 17.6 ml pipette. 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.

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Calculation

$$\text{Percent lactic acid} = \frac{\text{ml N/10 alkali} \times 0.0009 \times 100}{\text{grams of sample}}$$

II. Using N/9 sodium hydroxide: Milk, skim milk and buttermilk

Apparatus

Same as for I.

Reagents

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

Procedure

1. Put 10 ml of milk in a porcelain dish.
2. Add 0.5 ml of 1.6% solution of phenolphthalein.

Titrate with N/9 sodium hydroxide and follow the same procedures as in I.

Calculation

$$\text{Percent lactic acid} = \frac{W}{V}$$

Where W = volume of N/9 NaOH required (ml) and
V = volume of milk taken for analysis (10 ml)

iii. Using N/9 sodium hydroxide: Cream

Procedure

1. Put 10 ml of cream in a porcelain dish.
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 II.

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

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

8.1.5 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

- Ordinary 6-inch (15 cm) test tubes.
- Test-tube racks or blocks of wood with holes bored to fit the test tubes.

Reagents

The only reagent needed is a 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.

8.1.6 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 (and all liquids) boils at lower temperature and therefore the test is even more lenient.

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Apparatus

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

Reagents

None

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 failed if any curd forms.

8.1.7 Butterfat determination

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

The Gerber test

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

Milk

Apparatus

The apparatus required for butterfat content analysis comprises:

1. Gerber butyrometer calibrated to read 0–8% or 0–5% and graduated at 0.1% intervals.
2. Butyrometer stoppers.
3. Milk pipette — volume to match the butyrometer in use.
4. 10 ml double-bulb pipette* for pipetting sulphuric acid.
5. 1 ml bulb pipette* for pipetting amyl alcohol.
6. Thermometer to read 1–100°C
7. Water bath.
8. Gerber centrifuge.

Reagents

- 1.825 specific gravity sulphuric acid
- Amyl alcohol

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 of the milk, by ensuring that the milk flows gently down the inside of the butyrometer. It then rests on top of the acid.
4. Pipette or dispense 1 ml of amyl alcohol.
5. Clean the neck of the butyrometer with a 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. Then place the butyrometer in a water bath at 65°C for 5 minutes.
8. Centrifuge for 4 minutes at 1100 rpm.
9. Return the butyrometer to the water bath for 5 minutes, ensuring that the water level is high enough to heat the fat column.
10. Read the fat percentage. If necessary, the fat column can be adjusted by regulating the position of the stopper.

Hazards

- Sulphuric acid is toxic, highly corrosive and will 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.

* Alternatively, automatic dispensers can be used for delivering 10 ml of suphuric acid and 1 ml of amyl alcohol.

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- Avoid all spillage and dropping 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.

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

The procedure is the same as for whole milk up to and including the first centrifuging. The butyrometers are then placed in the water bath at 65°C, stoppers down, for 1 to 2 minutes and again centrifuged for 4 to 5 minutes. Then they are placed 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 to 0.25%	Add 0.02%
>0.25%	No correction required

Cream

Apparatus

The apparatus required for whole milk, except for the butyrometers and the 11 ml pipette, is supplemented by certain additional items for testing cream. The test bottles are standard Gerber cream butyrometers. Other items include a balance for weighing to 0.001 or 0.005 g; a stand to support the butyrometers on the balance or a stopper weighing funnel, and a wash bottle containing 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.

Cheese

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

Apparatus

Gerber cheese butyrometer stamped "3 g cheese". Other apparatus 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 counter-balanced piece of grease-proof paper.
2. Dispense 10 ml sulphuric acid into the butyrometer. Add 3 ml of water carefully so that it rests on the acid.
3. Wrap the 3 g of cheese in the grease-proof paper to form a cylinder that fits into the butyrometer.
4. Add a further 4 to 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 difficulty is experienced, place the butyrometer in the heated water bath and remove periodically for mixing until the cheese is fully dissolved.)

Cheese butyrometers are centrifuged and read as for milk and cream.

8.1.8 Determination of milk specific gravity

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.

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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. at 4°C 1 ml of milk weighs 1.032 g.

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°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 – 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°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°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 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 in equilibrium.
5. Allow the lactometer to float freely until it reaches equilibrium. Then 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.(°C)	17	18	19	20	21	22	23	24
Correction	−0.7	−0.5	−0.3	—	+0.3	+0.5	+0.8	+1.1

e.g. The lactometer reading is 30.5 and the temperature is 23°C.
Corrected lactometer = Lc = 30.5 + 0.8 = 31.3

Calculations

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

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

8.1.9 Determination of total solids (TS) and solids-not-fat (SNF) in milk

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.

$$\text{TS} = \frac{Lc}{4} + (1.22 \times \text{fat \%}) + 0.72$$

$$\text{SNF} = \text{TS} - \text{fat \%}$$

$$\text{or} \quad = \frac{Lc}{4} + (0.22 \times \text{fat \%}) + 0.72$$

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.

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8.1.10 Determination of moisture content of butter

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.
- Accurate moisture balance.
- 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:

$$\text{Moisture \%} = \frac{\text{Original weight} - \text{final weight}}{\text{Original weight}} \times 100$$

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9. CLEANING, SANITISING AND STERILISING DAIRY EQUIPMENT

Thorough cleaning and sanitising of all dairy equipment is an essential part of all 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 in the product and discolouration of the churn surface; and
- Contamination of the product with pathogens.

The cleaning of butter-making equipment was dealt with in the section on butter-making. 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 look neat. The processing room should also be well lit and ventilated, clean and neat. However, sanitation of processing equipment means more than having the equipment looking clean and neat.

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 in such a manner as to remove most of the micro-organisms present on its surface.
4. Sterilisation, where, in addition to being sanitised, the equipment has been treated in such a manner as 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.

Chemicals used for cleaning

Detergents are chemical agents that assist in the cleaning process by solubilising 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.

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.

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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.

Cleaning procedure

Before using any detergent or steriliser, remove as much of the product as possible from the surface of the equipment. Product not removed before washing is wasted.

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. After washing with cold water, 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. If the equipment is cleaned by hand it 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. After draining the solution, rinse the equipment at least three times with cold water to remove all traces of the detergent. If not removed, traces of detergent may be incorporated in subsequent batches of 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. After sanitising, 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.
- 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.

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10. 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.

10.1 SITE SELECTION

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

- Water supply and quality;
- Milk supply "catchment";
- Land availability and quality;
- Other buildings and activities near the site;
- Proximity to a road;
- Effluent disposal; and
- Good drainage.

10.1.1 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.

10.1.2 Land availability and quality

When selecting a site one should allow for possible future expansion. The site should be well drained.

10.1.3 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.

10.1.4 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.

10.1.5 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 meters and directed into a soak pit. Raw effluent should not be piped directly

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into a river or stream. If the effluent is not piped away from the building it will become a source of contamination and of foul smells.

10.2 TYPE OF BUILDING

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

10.2.1 Construction materials

The foundation and floor should be constructed from non-rotting material. 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.

10.2.2 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 for at least one metre if the superstructure of the building is not constructed from cement.

10.2.3 Effluent piping

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

10.2.4 Light

One or two screened windows 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.

10.2.5 Celling

Where possible, a ceiling should be included. This will help to improve the hygiene of the building and also keep the inside cool.

10.2.6 Door

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

10.3 ARRANGEMENT AND INSTALLATION OF EQUIPMENT

10.3.1 Arrangement

When arranging equipment one must consider:

- 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 byproduct.

If both cheese and butter are being made, the process lines should be located at either side of the dairy.

10.3.2 Installation

Some items of 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.

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APPENDIX 1

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

In order to go through this process, the composition of butter must be known accurately. This manual gives the method for moisture content. The salt content can be calculated, as the amount of salt added is known.

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

The milk SNF content can be taken as 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

$$S + C = 100$$

$$\frac{S \times Fs}{100} + \frac{C \times Fc}{100} = \frac{M \times Fm}{100}$$

or

$$0.001\,S + 0.35\,C = 4.0$$
$$0.001\,S + 0.001\,C = 0.1$$
$$0.349\,C = 3.9$$
$$C = 11.17$$

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

Therefore, fat losses in the skim milk

$$= \frac{88.83 \times 0.1}{100} = 0.0888 \text{ kg}$$

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

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 = percent fat in buttermilk = 0.5
B = weight of butter (after salting)
Fb = percent fat in butter = 81.3

$$BM + B = 11.17$$
$$0.005\,BM + 0.813\,B = 3.9$$
$$0.005\,BM + 0.005\,B = 0.05585$$
$$0.808\,B = 3.844$$
$$B = 4.75$$

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

The loss of fat is 0.032 kg

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

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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 at 18 cents per kilogram.

Therefore the total value of production

= 4.75 × 10	= 47.5 birr
= 95.25 × 0.18	= 17.1 birr
Total value	64.6 birr

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