2 OVERVIEW OF DAIRY PROCESSING

Primary production and dairy processing

The dairy industry is divided into two main production areas:

- the primary production of milk on farms—the keeping of cows (and other animals such as goats, sheep etc.) for the production of milk for human consumption;
- the processing of milk—with the objective of extending its saleable life. This objective is typically achieved by (a) heat treatment to ensure that milk is safe for human consumption and has an extended keeping quality, and (b) preparing a variety of dairy products in a semi-dehydrated or dehydrated form (butter, hard cheese and milk powders), which can be stored.

Focus of this guide

The focus of this document is on the processing of milk and the production of milk-derived products—butter, cheese and milk powder—at dairy processing plants. The upstream process of primary milk production on dairy farms is not covered, since this activity is more related to the agricultural sector. Similarly, downstream processes of distribution and retail are not covered.

Industry structure and trends

Dairy processing occurs world-wide; however the structure of the industry varies from country to country. In less developed countries, milk is generally sold directly to the public, but in major milk producing countries most milk is sold on a wholesale basis. In Ireland and Australia, for example, many of the large-scale processors are owned by the farmers as co-operatives, while in the United States individual contracts are agreed between farmers and processors.

Dairy processing industries in the major dairy producing countries have undergone rationalisation, with a trend towards fewer but larger plants operated by fewer people. As a result, in the United States, Europe, Australia and New Zealand most dairy processing plants are quite large.

Plants producing market milk and products with short shelf life, such as yogurts, creams and soft cheeses, tend to be located on the fringe of urban centres close to consumer markets. Plants manufacturing items with longer shelf life, such as butter, milk powders, cheese and whey powders, tend to be located in rural areas closer to the milk supply.

The general tendency world-wide, is towards large processing plants specialising in a limited range of products. There are exceptions, however. In eastern Europe for example, due to the former supply-driven concept of the market, it is still very common for 'city' processing plants to be large multi-product plants producing a wide range of products.

The general trend towards large processing plants has provided companies with the opportunity to acquire bigger, more automated and more efficient equipment. This technological development has, however, tended to increase environmental loadings in some areas due to the requirement for long-distance distribution.

Basic dairy processes have changed little in the past decade. Specialised processes such as ultrafiltration (UF), and modern drying processes, have increased the opportunity for the recovery of milk solids that were formerly discharged. In addition, all processes have become much more energy efficient and the use of electronic control systems has allowed improved processing effectiveness and cost savings.

2.1 Process overview

2.1.1 Milk production

The processes taking place at a typical milk plant include:

- receipt and filtration/clarification of the raw milk;
- separation of all or part of the milk fat (for standardisation of market milk, production of cream and butter and other fat-based products, and production of milk powders);
- pasteurisation;
- homogenisation (if required);
- deodorisation (if required);
- further product-specific processing;
- packaging and storage, including cold storage for perishable products;
- distribution of final products.

Figure 2–1 is a flow diagram outlining the basic steps in the production of whole milk, semi-skimmed milk and skimmed milk, cream, butter and buttermilk. In such plants, yogurts and other cultured products may also be produced from whole milk and skimmed milk.

2.1.2 Butter production

The butter-making process, whether by batch or continuous methods, consists of the following steps:

- preparation of the cream;
- destabilisation and breakdown of the fat and water emulsion;
- aggregation and concentration of the fat particles;
- formation of a stable emulsion;
- packaging and storage;
- distribution.

Figure 2–2 is a flow diagram outlining the basic processing system for a butter-making plant. The initial steps, (filtration/clarification, separation and pasteurisation of the milk) are the same as described in the previous section. Milk destined for butter making must not be homogenised, because the cream must remain in a separate phase.

After separation, cream to be used for butter making is heat treated and cooled under conditions that facilitate good whipping and churning. It may then be ripened with a culture that increases the content of diacetyl, the compound responsible for the flavour of butter. Alternatively, culture inoculation may take place during churning. Butter which is flavour enhanced using this process is termed lactic, ripened or cultured butter. This process is very common in continental European countries. Although the product is claimed to have a superior flavour, the storage life is limited. Butter made without the addition of a culture is called sweet cream butter. Most butter made in the English-speaking world is of this nature.

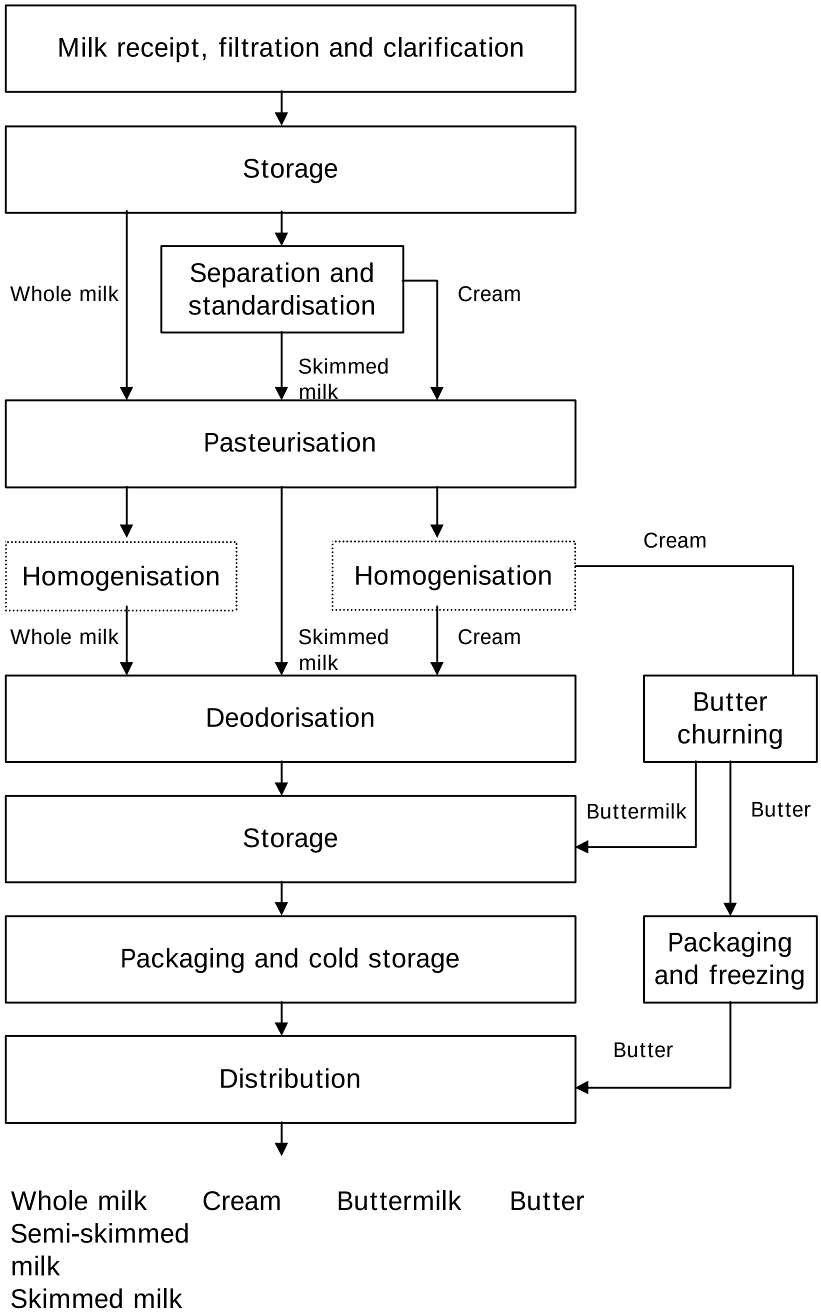

Figure 2–1 Flow diagram for processes occurring at a typical milk plant

Both cultured and sweet cream butter can be produced with or without the addition of salt. The presence of salt affects both the flavour and the keeping quality.

Butter is usually packaged in bulk quantities (25 kg) for long-term storage and then re-packed into marketable portions (usually 250 g or 500 g, and single-serve packs of 10–15 g). Butter may also be packed in internally lacquered cans, for special markets such as the tropics and the Middle East.

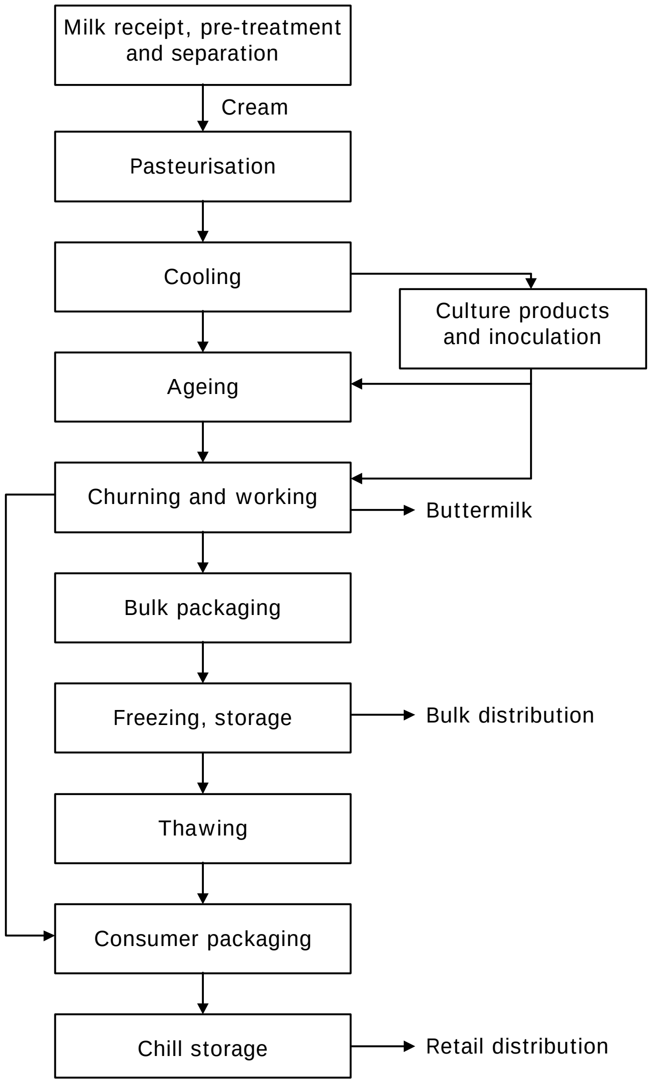

Figure 2–2 Flow diagram for a typical butter-making plant

2.1.3 Cheese production

Virtually all cheese is made by coagulating milk protein (casein) in a manner that traps milk solids and milk fat into a curd matrix. This curd matrix is then consolidated to express the liquid fraction, cheese whey. Cheese whey contains those milk solids which are not held in the curd mass, in particular most of the milk sugar (lactose) and a number of soluble proteins.

Figure 2–3 outlines the basic processes in a cheese-making plant. All cheese-making processes involve some or all of these steps.

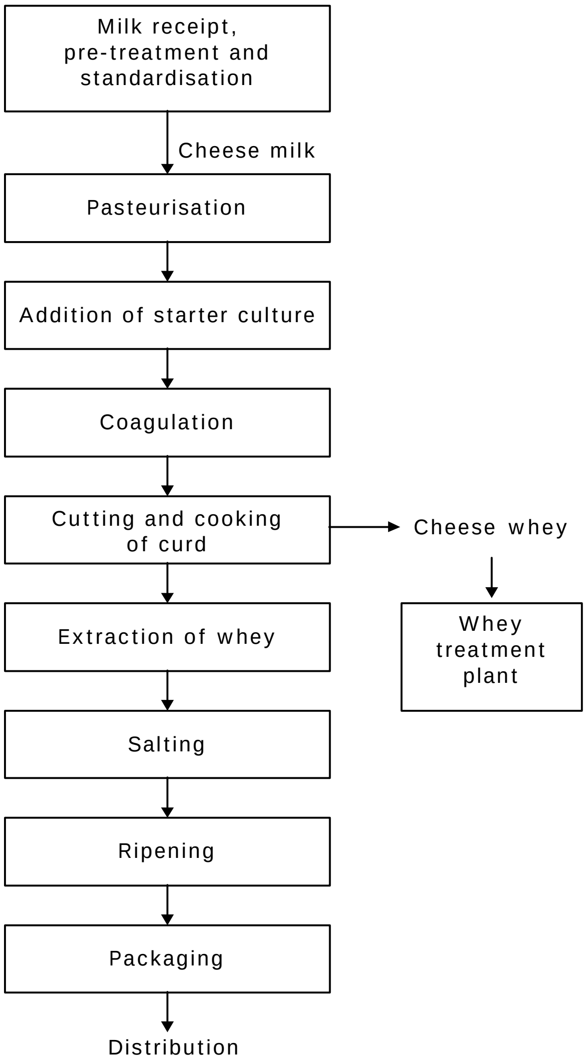

Figure 2–3 Flow diagram for a typical cheese plant

2.1.4 Milk powder production

Milk used for making milk powder, whether it be whole or skim milk, is not pasteurised before use. The milk is preheated in tubular heat exchangers before being dried. The preheating temperature depends on the season (which affects the stability of the protein in the milk) and on the characteristics desired for the final powder product.

The preheated milk is fed to an evaporator to increase the concentration of total solids. The solids concentration that can be reached depends on the efficiency of the equipment and the amount of heat that can be applied without unduly degrading the milk protein.

The milk concentrate is then pumped to the atomiser of a drying chamber. In the drying chamber the milk is dispersed as a fine fog-like mist into a rapidly moving hot air stream, which causes the individual mist droplets to instantly evaporate. Milk powder falls to the bottom of the chamber, from where it is removed. Finer milk powder particles are carried out of the chamber along with the hot air stream and collected in cyclone separators.

Milk powders are normally packed and distributed in bulk containers or in 25 kg paper packaging systems. Products sold to the consumer market are normally packaged in cans under nitrogen. This packaging system improves the keeping quality, especially for products with high fat content.

Figure 2–4 outlines the basic processes for the production of milk powder.

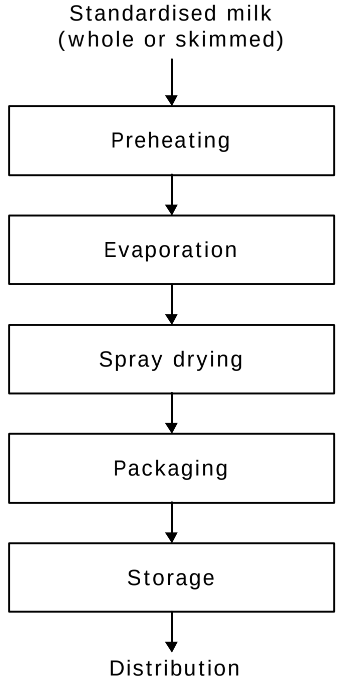

Figure 2–4 Flow diagram for a typical milk drying plant

2.2 Environmental impacts

This section briefly describes some of the environmental impacts associated with the primary production of milk and the subsequent processing of dairy products. While it is recognised that the primary production of milk has some significant environmental impacts, this document is predominantly concerned with the processing of dairy products.

2.2.1 Impacts of primary production

The main environmental issues associated with dairy farming are:

- the generation of solid manure and manure slurries, which may pollute surface water and groundwater;
- the use of chemical fertilisers and pesticides in the production of pastures and fodder crops, which may pollute surface water and groundwater;
- the contamination of milk with pesticides, antibiotics and other chemical residues.

Manure wastes

In most cases, solid manure is applied to pastures and cultivated land. The extent of application, however, may be restricted in some regions. Dairy effluent and slurries are generally held in some form of lagoon to allow sedimentation and biological degradation before they are irrigated onto land. Sludge generated from biological treatment of the dairy effluent can also be applied to pastures, as long as it is within the allowable concentrations for specified pollutants, as prescribed by regulations. Sludge can also be used in the production of methane-rich biogas, which can then be used to supplement energy supplies.

Manure waste represents a valuable source of nutrients. However improper storage and land application of manure and slurries can result in serious pollution of surface waters and groundwater, potentially contaminating drinking water supplies.

Chemical fertilisers

The extensive use of chemical fertilisers containing high levels of nitrogen has resulted in pollution of the groundwater and surface waters in many countries.

Nitrite in drinking water is known to be carcinogenic, and nitrite levels in drinking water that exceed 25–50 mg/L have been linked to cyanosis in newborn infants (‘blue babies’).

Compounds containing nitrogen and phosphorus, if discharged to surface water, can lead to excessive algal growth (eutrophication). This results in depleted dissolved oxygen levels in the water, thereby causing the death of fish and other aquatic species. In sensitive areas, therefore, the rate and manner of application of chemical fertilisers are critical.

Pesticides

The use of pesticides has been recognised as an environmental concern for many agricultural activities. Toxic pesticides, some of which biodegrade very slowly, can accumulate in body tissues and are harmful to ecosystems and to human health. Pesticides can end up in agricultural products, groundwater and surface waters, and in extreme cases can enter the human food chain through milk.

Milk contamination

For the past few decades, the contamination of milk with antibiotics has been an issue of concern. This is due to the overuse of antibiotics for treatment of cattle diseases, particularly mastitis. It has been brought under control in most countries with developed dairy industries, through strict limitations on the use of antibiotics, regular testing of milk for antibiotic residues, rigorous enforcement of regulations, and education.

In some countries, considerable attention has also been paid to the screening of milk supplies for traces of radioactivity, and most countries now apply acceptance limits for raw and imported milk products. Even the slightest levels of contamination in milk can be serious, because pollutants are concentrated in the processing process.

2.2.2 Impacts of dairy processing

As for many other food processing operations, the main environmental impacts associated with all dairy processing activities are the high consumption of water, the discharge of effluent with high organic loads and the consumption of energy. Noise, odour and solid wastes may also be concerns for some plants.

Water consumption

Dairy processing characteristically requires very large quantities of fresh water. Water is used primarily for cleaning process equipment and work areas to maintain hygiene standards.

Effluent discharge

The dominant environmental problem caused by dairy processing is the discharge of large quantities of liquid effluent. Dairy processing effluents generally exhibit the following properties:

- high organic load due to the presence of milk components;
- fluctuations in pH due to the presence of caustic and acidic cleaning agents and other chemicals;
- high levels of nitrogen and phosphorus;
- fluctuations in temperature.

If whey from the cheese-making process is not used as a by-product and discharged along with other wastewaters, the organic load of the resulting effluent is further increased, exacerbating the environmental problems that can result.

In order to understand the environmental impact of dairy processing effluent, it is useful to briefly consider the nature of milk. Milk is a complex biological fluid that consists of water, milk fat, a number of proteins (both in suspension and in solution), milk sugar (lactose) and mineral salts.

Dairy products contain all or some of the milk constituents and, depending on the nature and type of product and the method of manufacturing, may also contain sugar, salts (e.g. sodium chloride), flavours, emulsifiers and stabilisers.

For plants located near urban areas, effluent is often discharged to municipal sewage treatment systems. For some municipalities, the effluent from local dairy processing plants can represent a significant load on sewage treatment plants. In extreme cases, the organic load of waste milk solids entering a sewage system may well exceed that of the township's domestic waste, overloading the system.

In rural areas, dairy processing effluent may also be irrigated to land. If not managed correctly, dissolved salts contained in the effluent can adversely affect soil structure and cause salinity. Contaminants in the effluent can also leach into underlying groundwater and affect its quality.

In some locations, effluent may be discharged directly into water bodies. However this is generally discouraged as it can have a very negative impact on water quality due to the high levels of organic matter and resultant depletion of oxygen levels.

Energy consumption

Electricity is used for the operation of machinery, refrigeration, ventilation, lighting and the production of compressed air. Like water consumption, the use of energy for cooling and refrigeration is important for ensuring good keeping quality of dairy products and storage temperatures are often specified by regulation. Thermal energy, in the form of steam, is used for heating and cleaning.

As well as depleting fossil fuel resources, the consumption of energy causes air pollution and greenhouse gas emissions, which have been linked to global warming.

Solid wastes

Dairy products such as milk, cream and yogurt are typically packed in plastic-lined paperboard cartons, plastic bottles and cups, plastic bags or reusable glass bottles. Other products, such as butter and cheese, are wrapped in foil, plastic film or small plastic containers. Milk powders are commonly packaged in multi-layer kraft paper sacs or tinned steel cans, and some other products, such as condensed milks, are commonly packed in cans.

Breakages and packaging mistakes cannot be totally avoided. Improperly packaged dairy product can often be returned for reprocessing; however the packaging material is generally discarded.

Emissions to air

Emissions to air from dairy processing plants are caused by the high levels of energy consumption necessary for production. Steam, which is used for heat treatment processes (pasteurisation, sterilisation, drying etc.) is generally produced in on-site boilers, and electricity used for cooling and equipment operation is purchased from the grid. Air pollutants, including oxides of nitrogen and sulphur and suspended particulate matter, are formed from the combustion of fossil fuels, which are used to produce both these energy sources.

In addition, discharges of milk powder from the exhausts of spray drying equipment can be deposited on surrounding surfaces. When wet these deposits become acidic and can, in extreme cases, cause corrosion.

Refrigerants

For operations that use refrigeration systems based on chlorofluorocarbons (CFCs), the fugitive loss of these gases to the atmosphere is an important environmental consideration, since CFCs are recognised to be a cause of ozone depletion in the atmosphere. For such operations, the replacement of CFC-based systems with non- or reduced-CFC systems is thus an important issue.

Noise

Some processes, such as the production of dried casein, require the use of hammer mills to grind the product. The constant noise generated by this equipment has been known to be a nuisance in surrounding residential areas. The use of steam injection for heat treatment of milk and for the creation of reduced pressure in evaporation processes also causes high noise levels.

A substantial traffic load in the immediate vicinity of a dairy plant is generally unavoidable due to the regular delivery of milk (which may be on a 24-hour basis), deliveries of packaging and the regular shipment of products.

Noise problems should be taken into consideration when determining plant location.

Hazardous wastes

Hazardous wastes consist of oily sludge from gearboxes of moving machines, laboratory waste, cooling agents, oily paper filters, batteries, paint cans etc. At present, in western Europe some of these materials are collected by waste companies. While some waste is incinerated, much is simply dumped.

2.3 Environmental indicators

Environmental indicators are important for assessing Cleaner Production opportunities and for assessing the environmental performance of one dairy processing operation relative to another. They provide an indication of resource consumption and waste generation per unit of production.

Figure 2–5 is a generic flowchart of the overall process including resource inputs and waste outputs. The sections that follow provide a discussion of the key inputs and outputs. Where available, quantitative data are provided.

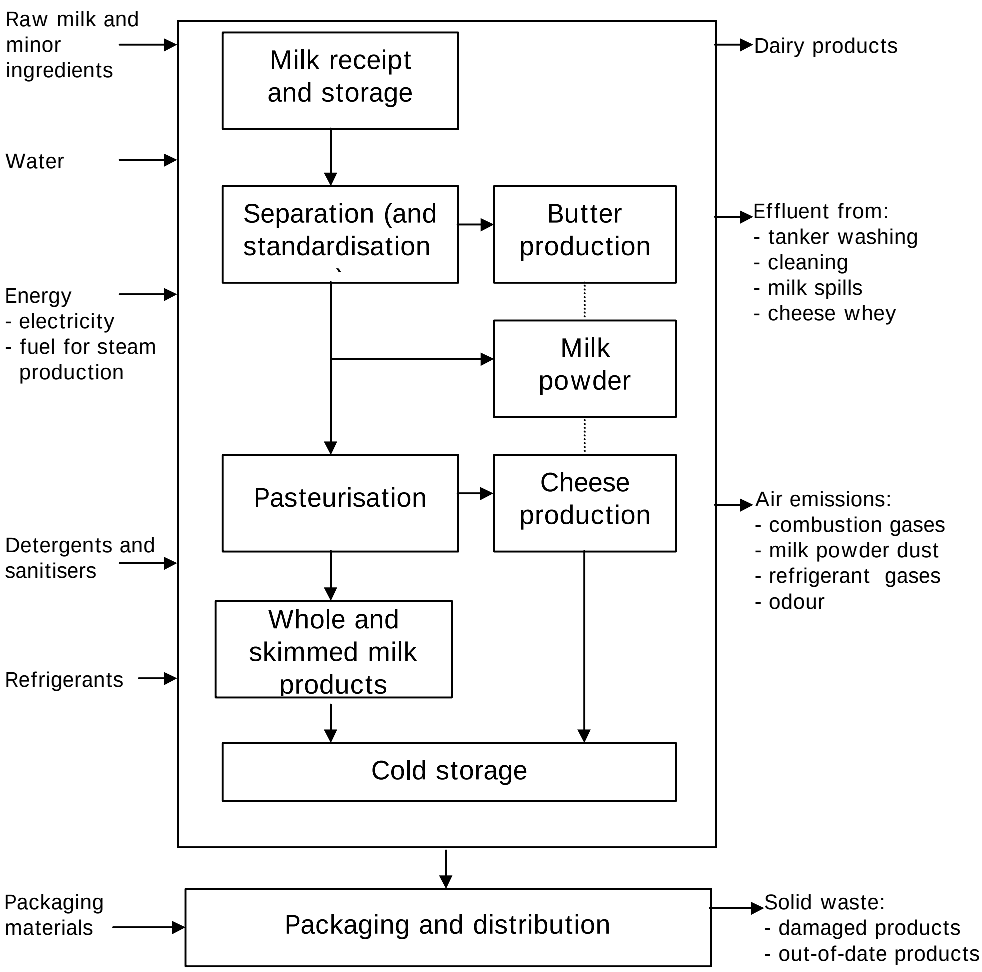

Figure 2–5 Inputs and outputs of a dairy

2.3.1 Water consumption

As with most food processing operations, water is used extensively for cleaning and sanitising plant and equipment to maintain food hygiene standards. Table 2–1 shows the areas of water consumption within a dairy processing plant, and gives an indication of the extent to which each area contributes to overall water use.

Due to the higher costs of water and effluent disposal that have now been imposed in some countries to reflect environmental costs, considerable reduction in water consumption has been achieved over the past few decades in the dairy processing industry. Table 2–2 shows the reductions in water consumption per kilogram of product that have been achieved over this period. These improvements are attributed to developments in process control and cleaning practices.

At modern dairy processing plants, a water consumption rate of 1.3–2.5 litres water/kg of milk intake is typical, however 0.8–1.0 litres water/kg of milk intake is possible (Bylund, 1995). To achieve such low consumption requires not only advanced equipment, but also very good housekeeping and awareness among both employees and management.

Table 2–1 Areas of water consumption at dairy processing plants [1]

Area of use	**Consumption** (L/kg product)	**Percentage of total**
Locker room	0.01–1.45	2%
Staff use	0.02–0.44	2%
Boiler	0.03–0.78	2%
Cold storage	0.03–0.78	2%
Receipt area	0.11–0.92	3%
Filling room	0.11–0.41	3%
Crate washer	0.18–0.75	4%
Cooling tower	0.20–1.8	5%
Cleaning	0.32–1.76	8%
Cheese room	0.06–20.89	13%
Utilities	0.56–4.39	16%
Incorporated into products	1.52–9.44	40%
TOTAL	**2.21–9.44**	**100**%

[1] Danish EPA, 1991

Table 2–2 Trend towards reduced water consumption at dairy processing plants

Water consumption (L/kg milk)		
	1973[1]	**1990s**[2]
Low consumption	2.21	
Medium consumption	3.25	1.3–2.5
High consumption	9.44	

[1] Jones, 1974

[2] Danish EPA, 1991

2.3.2 Effluent discharge

Dairy processing effluent contains predominantly milk and milk products which have been lost from the process, as well as detergents and acidic and caustic cleaning agents. The constituents present in dairy effluent are milk fat, protein, lactose and lactic acid, as well as sodium, potassium, calcium and chloride. Milk loss to the effluent stream can amount to 0.5–2.5% of the incoming milk, but can be as high as 3–4%.

A major contributing factor to a dairy plant's effluent load is the cumulative effect of minor and, on occasions, major losses of milk. These losses can occur, for example, when pipework is uncoupled during tank transfers or equipment is being rinsed. Table 2–3 provides a list of the sources of milk losses to the effluent stream.

The organic pollutant content of dairy effluent is commonly expressed as the 5-day biochemical oxygen demand (BOD_5) or as chemical oxygen demand (COD). One litre of whole milk is equivalent to approximately 110,000 mg BOD_5 or 210,000 mg COD.

Concentrations of COD in dairy processing effluents vary widely, from 180 to 23,000 mg/L. Low values are associated with milk receipt operations and high values reflect the presence of whey from the production of cheese. A typical COD concentration for effluent from a dairy plant is about 4000 mg/L. This implies that 4% of the milk solids received into the plant is lost to the effluent stream, given that the COD of whole milk is 210,000 mg/L and that effluent COD loads have been estimated to be approximately 8.4 kg/m^3 milk intake (Marshall and Harper, 1984).

A Danish survey (see text box below) found that effluent loads from dairy processing plants depend, to some extent, on the type of product being produced. The scale of the operation and whether a plant uses batch or continuous processes also have a major influence, particularly for cleaning. This is because small batch processes requires more frequent cleaning. The tendency within the industry towards larger plants is thus favourable in terms of pollutant loading per unit of production.

Water consumption survey for Danish dairy processing plants

A survey of 72 Danish dairy companies operating a total of 134 processing plants was conducted in 1989 (Danish EPA, 1991). The product mix of the companies surveyed was as follows: 44 dairies produced butter, 90 produced cheese, 29 were market milk plants and 11 produced concentrates including milk powder. The plants surveyed were all technologically advanced and most claimed that they had reduced the pollutant load of their effluents by 30–50% compared with previous years. The survey found that on average each tonne of milk processed resulted in the production of 1.3 m^3 of effluent with the following characteristics:

COD	2000 mg/L
BOD_5	1500 mg/L
Fat	150 mg/L
Total nitrogen	100 mg/L
Total phosphorus	30 mg/L

Table 2–3 Sources of milk losses to the effluent stream [1]

Process area	Source of milk loss
Milk receipt and storage	• Poor drainage of tankers • Spills and leaks from hoses and pipes • Spills from storage tanks • Foaming • Cleaning operations
Pasteurisation and ultra heat treatment	• Leaks • Recovery of downgraded product • Cleaning operations • Foaming • Deposits on surfaces of equipment
Homogenisation	• Leaks • Cleaning operations
Separation and clarification	• Foaming • Cleaning operations • Pipe leaks
Market milk production	• Leaks and foaming • Product washing • Cleaning operations • Overfilling • Poor drainage • Sludge removal from separators/clarifiers • Damaged milk packages • Cleaning of filling machinery
Cheese making	• Overfilling vats • Incomplete separation of whey from curds • Use of salt in cheese making • Spills and leaks • Cleaning operations
Butter making	• Vacreation and use of salt • Cleaning operations
Milk powder production	• Spills during powder handling • Start-up and shut-down processes • Plant malfunction • Stack losses • Cleaning of evaporators and driers • Bagging losses

[1] EPA Victoria 1997.

Due to the traditional payment system for raw milk (which is based on the mass or volume delivered plus a separate price or premium for the weight of milk fat), the dairy processing industry has always tried to minimise loss of milk fat. In many countries the payment system now recognises the value of the non-fat milk components. Systems that control the loss of both fat and protein are now common in the industrialised world, but less so in the developing world.

The disposal of whey produced during cheese production has always been a major problem in the dairy industry. Whey is the liquid remaining after the recovery of the curds formed by the action of enzymes on milk. It comprises 80–90% of the total volume of milk used in the cheese making process and contains more than half the solids from the original whole milk, including 20% of the protein and most of the lactose. It has a very high organic content, with a COD of approximately 60,000 mg/L (Morr, 1992). Only in the past two decades have technological advances made it economically possible to recover soluble proteins from cheese whey and, to some extent, to recover value from the lactose.

Most dairies are aware that fat and protein losses increase the organic load of the effluent stream and, even in the developing world, the use of grease traps has been common for some decades. Many companies, however, do not take any action to reduce the organic pollution from other milk components. It is becoming more common for dairy companies to be forced by legal or economic pressures to reduce the amount and concentration of pollutants in their effluent streams.

Therefore, at most sites, wastewater treatment or at least pretreatment is necessary to reduce the organic loading to a level that causes minimal environmental damage and does not constitute a health risk. The minimum pretreatment is usually neutralisation of pH, solids sedimentation and fat removal.

2.3.3 Energy consumption

Energy is used at dairy processing plants for running electric motors on process equipment, for heating, evaporating and drying, for cooling and refrigeration, and for the generation of compressed air.

Approximately 80% of a plant's energy needs is met by the combustion of fossil fuel (gas, oil etc.) to generate steam and hot water for evaporative and heating processes. The remaining 20% or so is met by electricity for running electric motors, refrigeration and lighting.

The energy consumed depends on the range of products being produced. Processes which involve the concentration and drying of milk, whey or buttermilk for example, are very energy intensive. The production of market milk at the other extreme involves only some heat treatment and packaging, and therefore requires considerably less energy. Table 2–4 provides some indicative figures of specific energy consumption of different dairy products.

Table 2–4 Specific energy consumption for various dairy products [1]

Product	**Electricity consumption** (GJ/tonne product)	**Fuel consumption** (GJ/tonne product)
Market milk	0.20	0.46
Cheese	0.76	4.34
Milk powder	1.43	20.60
Butter	0.71	3.53

[1] Joyce and Burgi, 1993. (based on a survey of Australian dairy processors in 1981–82)

Energy consumption will also depend on the age and scale of a plant as well as the level of automation. To demonstrate this, Table 2–5 provides examples of energy consumption rates for a selection of Australian plants processing market milk.

Table 2–5 Energy consumption for a selection of milk plants [1]

Type of plant	**Total energy consumption** (GJ/tonne milk processed)
Modern plant with high-efficiency regenerative pasteuriser and modern boiler	0.34
Modern plant using hot water for processing	0.50
Old, steam-based plant	2.00
Range for most plants	0.5–1.2

[1] Joyce and Burgi, 1993. (based on a survey of Australian dairy processors in 1981–82)

Plants producing powdered milk exhibit a wide range of energy efficiencies, depending on the type of evaporation and drying processes that are used. Energy consumption depends on the number of evaporation effects (the number of evaporation units that are used in series) and the efficiency of the powder dryer. Table 2–6 provides examples of how different evaporation and drying systems can affect the energy efficiency of the process.

Substantial increases in electricity use have resulted from the trend towards automated plant with associated pumping costs and larger evaporators as well as an increase in refrigeration requirements.

High consumption of electricity can also be due to the use of old motors, excessive lighting or possibly a lack of power factor correction.

Table 2–6 Energy consumption for evaporation and drying systems [1]

Type of evaporation and drying system	**Total energy consumption** (GJ/tonne product)
5-effect evaporator and 2-stage drier	13–15
3-effect evaporator and 1-stage drier	22–28
2-effect evaporator and 1-stage drier	40–50

[1] Joyce and Burgi, 1993. (based on a survey of Australian dairy processors in 1981–82)