CHAPTER 10

MILK COOLING METHODS: IMPORTANCE AND POTENTIAL USE

BHAVESH B. CHAVHAN, A. K. AGRAWAL, S. S. CHOPADE, and G. P. DESHMUKH

CONTENTS

10.1 INTRODUCTION

The first operation in a dairy plant is reception, chilling and storage of milk. Raw milk is pumped from the dump tank to the storage tank through a filter and chillers. The purpose of storage tank is to hold milk at low temperature so as to maintain continuity in milk processing operations and prevent any deterioration in the quality during holding and processing period. The milk may arrive at a chilling center or dairy plant in cans. After unloading the cans, milk is chilled and stored in storage tanks. Storage tanks are used to store raw or even pasteurized milk. Milk leaves the udder at body temperature of about 38°C. The bacterial load may grow rapidly and bring about curdling and other undesirable changes if milk is held at the ambient temperature. Freshly drawn raw milk should be promptly cooled and held at 4°C till processing to preserve it against bacterial deterioration. Milk may be held in chilled condition (<4°C) in the tank for up to 72 hours between reception and processing. Normally the milk storage capacity should be equivalent to one day's intake [4].

This chapter presents methods of milk cooling.

10.2 IMPORTANCE OF COOLING

Milk leaves the udder at body temperature containing only a few microorganisms. Normally milk contains bacteria coming from the animal's udder, milk vessels and operators. When the milk leaves the udder, bacteria grow well at the ambient temperature (20–40°C) and milk starts deteriorating. Bacterial growth factor goes down to 1.05 at 5°C and 1.00 at 0°C. Critical temperature for bacterial growth is 10°C. The growth factor at 10°C is 1.80 which rises to 10.0 at 15°C. Hence, freshly drawn raw milk should be promptly cooled to 5°C or below and held at that temperature till it is processed [6].

The growth factor increases rapidly, if growth is not checked immediately by chilling the milk. Chilling is necessary after receiving milk at collection/chilling center. Chilled milk can easily and safely be transported without having appreciable deteriorative changes due to microbial growth. Thus, raw milk is chilled to: (a) limit the growth of bacteria, (b) minimize micro-induced changes, and (c) maximize its shelf life. However, chilling of milk involves additional expense, which increases the cost of processing. Importantly, chilling process does not kill microorganisms nor it renders milk safe for human consumption. It is only a means of checking the growth of microorganisms for a certain period.

10.3 EFFECTS ON MICROBIAL GROWTH

Generally, milk is cooled immediately after milking to below 10°C within 4 hours to prevent/retard the multiplication of thermophilic and mesophilic bacteria including disease producing and food poisoning organisms until the milk reaches the dairy. The extent of control of growth of microorganisms is dependent on type of organisms. *Staphylococci* do not grow below 10°C. Growth stops for most types of *E. coli*, *B. proteus* and *Micrococci* between 0°C and 5°C. If milk is stored cold for too long time, there can be an undesirable increase in psychotropic organisms, which produce extremely heat resistant lipases and proteases.

The time factor is critical in arresting bacterial growth in fresh milk. As milk from the udder of healthy cows has a low bacterial count. There is a lag phase immediately after milking, for around 4 hours, before bacterial multiplication begins to grow. The quicker milk is cooled, the better is the quality. The milk is cooled immediately after milking to 4°C or below and held at that temperature till it is processed. The effect of storage temperature on microbial growth in raw milk is shown in Table 10.1.

10.3.1 EFFECTS ON STORAGE QUALITY OF MILK

Fresh raw milk is cooled to 4°C to extend its shelf-life (freshness). At this temperature, the activity of enzymes, the growth of microorganisms and metabolic processes are slowed down. As a result, prolonged holding of chilled milk is bound to cause significant deteriorative alterations in keeping quality of milk [2]. In addition, cooling causes a considerable dissociation of b-casein, calcium and phosphate ions and proteases from the casein micelles [3]. The milk loses its suitability for cheese making, coagulation times are increased and the curd tension of the coagulum is less.

TABLE 10.1 Effects of Storage Temperature on Microbial Growth in Raw Milk

Raw milk storage temperature (°C) for a period of 18 hours	Bacterial growth factor*
0	1.00
5	1.05
10	1.80
15	10.00
20	200.00
25	1,20,000.00

* Final count = (bacterial growth factor) x (Initial count of bacteria).

Chemical and biochemical processes are considerably slowed down by cooling. However, milk, which has been stored, sometime has a bitter off-flavor. Enzymes and microorganisms can cause chemical changes, which are accompanied by a low pH value and change in nitrogen-containing compounds. Psychrophilic microorganisms cause proteolysis of casein and, together with enzymes, also that of albumin. Protein breakdown products (polypeptides) are formed. Certain bacteria are responsible for the hydrolysis of fats causing rancid flavor development. Several enzymes such as oxidize catalyze and reductase are active for a long time, even at 0°C. Hence, if the time between milk reception and processing is 2 to 3 days, the storage temperature should be kept between 2 and 5°C for minimum effect on keeping quality of milk.

10.3.2 EFFECTS ON PHYSICO-CHEMICAL PROPERTIES OF MILK

10.3.2.1 Failure to Rennet/Acid Coagulation

The failure of casein to coagulate at 2°C either at pH 4.7 or after rennet treatment has been utilized in the development of continuous cheese making process, where the milk is either acidified or renneted at 2°C and the temperature is subsequently raised to about 15.6°C or 30°C to affect coagulation.

10.3.2.2 Failure to Coagulate at Iso-Electric Point

Milk fails to coagulate at 2°C after adjusting to the iso-electric point (pH) of casein. At 2–3°C, there is an increase in the diffusible inorganic salts and a change in the casein micelle structure. Some micellar casein is converted to a non-micellar or soluble form (e.g., b-casein). At 2°C, the pH of the milk must be reduced to 4.3 to affect complete casein coagulation, whereas at 30°C the recovery of the casein at pH 4.6 was nearly complete. Also the properties of casein obtained by acid precipitation at 2°C and pH 4.3, and at 30°C and pH 4.6 were slightly different.

10.3.2.3 Increase in Viscosity

Storage of milk at 2 to 5°C, both raw and pasteurized, caused an increase in the viscosity of the product which may be related to changes in the protein system, since viscosity is influenced largely by the colloidal components of milk. Probably, conversion of colloidal calcium partly to soluble form may uncoil the casein micelle. The change in viscosity with storage at low temperature (2 to 5°C) was greatest during the first 24 hours and reaches maximum after about 72 hours.

10.3.2.4 Decrease in Cheese Curd Firmness

The cold aging of milk increased the rennet coagulation time at 30°C. The increased coagulation time was inversely related to the ratio of colloidal calcium-phosphate, and could be reversed by heating to 40°C for 10 minutes or by addition of calcium chloride to the milk prior to cold aging [8].

10.3.2.5 Increased Hydrolytic Rancidity

Cold storage of milk below 7°C is associated with an increase in the rate of development of rancidity. Cooling tends to dissociate the casein micelle and increases the total available lipase in the milk system. Subsequent treatment to milk (warming, agitation, etc.) bring lipases into contact with fat globules and liberate free fatty acids to produce rancidity in milk.

10.3.2.6 Increased Foaming

Cold milk foams readily. Milk proteins concentrate in the lamellae of the foam where b-lacto globulin acts as a surface active agent. Foams are formed by the preferential adsorption of surface active materials at an air-liquid interface with orientation of the material to form an air bubble.

10.3.2.7 Physical Structure of Fat Globules

Crystal structure and size vary as a function of both cooling rate and cooling temperature and regulate the hardness of the milk fat. More fat passes into the solid state by direct cooling than in stepwise cooling. The sensitivity of the fat globule membrane to shear and subsequent release of free fat is greater in milk that has a higher proportion of solid to liquid fat. Thus, milk rapidly cooled, to 0–5°C, is more sensitive to shear damage than that is cooled more slowly and in a stepwise manner [5].

10.4 EQUIPMENT AND METHODS OF CHILLING (APPENDIX A)

Cooling is the predominant method of maintaining milk quality during collection. The most important factor next to hygienic production of milk is the time between completion of milking and reducing the temperature low enough to restrict bacterial growth. Whatever the method of cooling, the faster the temperature is reduced from 37°C at milking, the better will be the resultant milk quality. Selection of a suitable method and equipment for prompt cooling, for example, chilling milk is dependent upon the available facilities at the moment keeping in view the volume of milk handling and time for cooling and keeping it cold till reaches for processing. Various methods of cooling of milk are described in the following subsections.

10.4.1 CAN (CONTAINER) IMMERSION

The fresh milk immediately after milking is placed in a container (preferably metal can) through strainer. The cans are gently lowered into a tank containing cooled water. The water level in the tank should be lower than the level of milk in cans to prevent water entering into the milk. Cooling of milk will slowly take place and if the water is cold enough, the milk temperature will be reduced low enough to allow the milk to be marketed/processed. The milk inside the cans may be stirred with the help of plunger for uniform quick cooling. In this method, a much smaller refrigeration unit is needed. The cans are kept cooled at the desired temperature (5–7°C) and the capacity of the unit is 200–280 liters of milk.

10.4.2 SURFACE COOLER

An improvement of water cooling is a metal surface cooler, where water flows through the inner side and milk flows over the outer surface in a thin layer (Figure 10.1). The milk is distributed over the outer surfaces of the cooling tubes from the top by means of a distributor pipe and flows down in a continuous thin stream. The cooling medium (mostly chilled water) is circulated in the opposite direction through inside of the tubes. A well designed water cooler will reduce milk temperature almost instantaneously. The cooled milk is received below in a receiving trough, from which it is discharged by gravity or a pump. It can be either an individual unit or cabinet type. The latter consists of two or more individual units, compactly assembled and enclosed in a cabinet. It is usually larger than those used on the farm/chilling center.

10.4.2.1 Advantages

- Transfers heat rapidly and efficiently.
- Relatively in-expensive.
- Aerates the milk and thus improves the flavor.

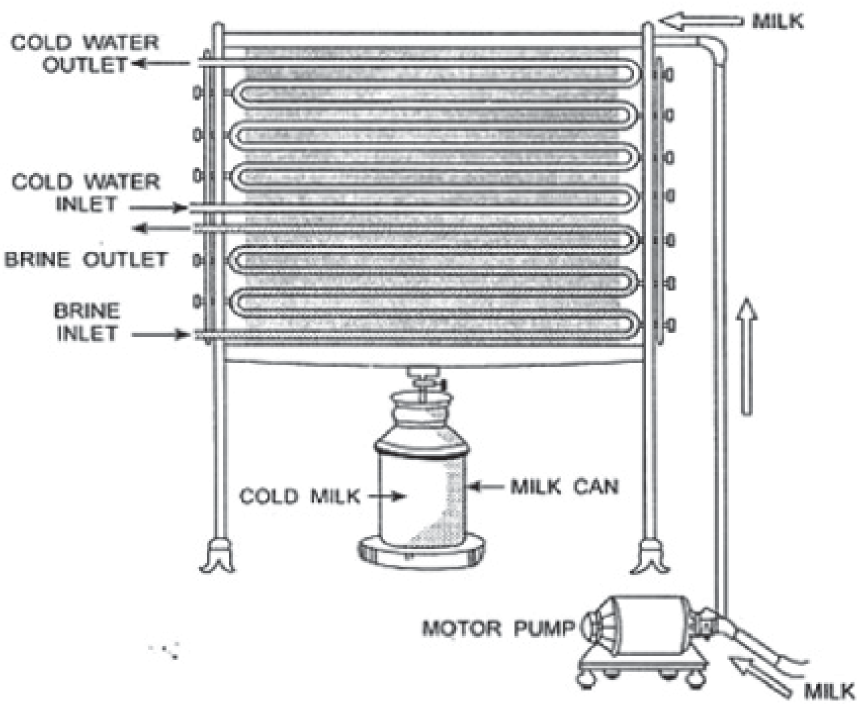

FIGURE 10.1 Surface cooler.

10.4.2.2 Disadvantages

- Requires constant attention of flow rate.
- Greater chances for air-borne contamination.

10.4.3 PLATE HEAT EXCHANGER (PHE)

The PHE is very effective equipment for chilling of milk in commercial dairy plants. It is widely used for large scale cooling of milk of 5000 to 60,000 liters/day at the chilling centers. This method of chilling is efficient, more hygienic, involves less manual labor and cost effective. Several stainless steel plates are mounted on a solid stainless steel frame in which the milk to be chilled and chilling water flow alternatively and countercurrently (Figure 10.2).

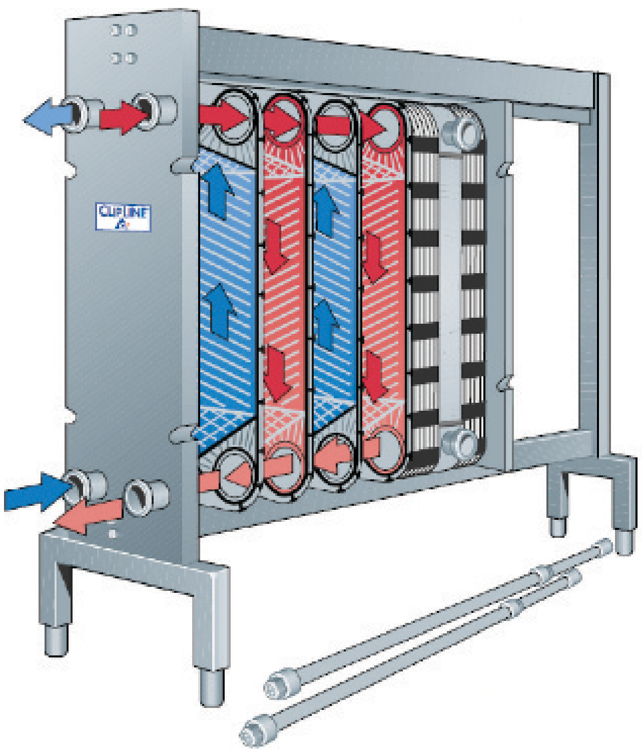

FIGURE 10.2 Plate heat exchanger.

The number and size of plates in the exchanger depend upon the capacity of the plant. It is widely used for large scale cooling of milk of 5000 to 60,000 liters/day at the chilling centers. They are efficient, compact and easily cleanable. In chillers, the gasket plates are tightly held between the plates. These plates are so arranged that milk flows on one side of plate and cooling medium (usually chilled water) on the other. There is a counter current flow between the milk and the chilled water through alternate plates. It helps in efficient transfer of heat to the cooling medium resulting in quick chilling of milk. The chilled milk flows from the plate cooler to the insulated storage tank at 4°C. A mechanical refrigeration system (IBT) is needed [7].

10.4.4 TUBULAR COOLER

This consists of two concentric tubes: inner tube usually carries the milk to be chilled while cold water is passing through the hollow space in between the pipes. The length and diameter of both the tubes are determined according to the capacity of the plant. The flow of the milk and chilled water is in opposite direction, for example, counter-current. The tubular cooler is efficient, where milk is not exposed to atmosphere.

10.4.5 MILK COOLER

This consists of a double jacketed vat fitted with a mechanical agitator. It has provision for circulation of chilled water, which comes from the chilled water tank. Normally, milk is chilled and subsequently stored at low temperature until transported to processing units for further processing. Bulk milk coolers are generally installed at chilling centers. Bulk tank coolers are run by mechanical refrigeration system, which cools the milk rapidly. These coolers maintain the temperature automatically during storage. Milk can be poured directly from milking pails into the tanks. This method is suitable for handling 500–2500 liters/day. It is widely used at village level milk collection centers. From the bulk milk cooler (BMC), the milk is pumped to the insulated tankers for transportation to dairy plants. The BMC uses horizontal or vertical cylindrical tanks with inner jacket and insulated body on the other side. There is provision of inner shell of the tank or direct expansion refrigerant coil for cooling. Milk is directly poured into the tank or pumped into the tank. Milk remains in contact with the inner shell of the tank for cooling it to 4°C. The agitator is provided for uniform cooling.

10.4.6 ROTOR FREEZE

In this system, evaporating unit cools the water, which in turn cools the milk in can. Several cans of milk can be cooled at a time. Rotor freeze provides spray of chilled water outside the cans obtained by mechanical refrigeration system and passing through the perforated tubes around the neck of the can. With this system, milk temperature is brought down to 10°C from 35°C within 15 minutes.

10.4.7 BRINE COOLING

The direct expansion coil is used to cool brine, which is then circulated by a pump around the product to be cooled. Brine system of cooling may be of: (a) brine circulating type, (b) brine storage type, and (c) congealing-tank type. This system has the advantage of being safe with ammonia and of causing less damage in case of a leakage and the temperature can be easily controlled. It allows heavy refrigerating loads of short duration to be carried with a system having a much smaller compressor than direct expansion system. The overall thermal efficiency of a brine system is usually less than the direct expansion system on account of the one extra heat transfer and the added radiation losses.

10.4.8 ICE COOLING

Ice, produced by commercial ice plants, is used in some countries to cool milk. The use of ice for cooling is generally fairly expensive and not particularly effective due to the problems in getting an optimum and rapid heat transfer from the liquid milk to the solid ice.

10.4.9 CAN COOLING

In this method, ice is placed in a metal container, known as ice gum or ice cone, which is inserted into the can of milk. This permits more effective heat exchange rate by giving off latent heat of ice and sensible heat of melted water, but reduces the volume of milk that can be carried in the milk can. When ice is completely melted in the ice cone and there is no more heat transfer, the water is thrown and fresh ice pieces are put in. The process of cooling milk by this method continues even during transportation from collection centers to processing unit.

10.4.10 DIRECT ADDITION OF ICE

Sometimes cooling of milk is done by direct putting ice into the milk. While this achieves an effective transfer of energy, and reasonably rapid cooling, it has a major disadvantage of diluting the milk with water, which will require removal at subsequent processing or the sale of adulterated milk.

10.4.11 MECHANICAL COOLING

Mechanical refrigeration system is the most effective means of arresting bacterial growth by lowering milk temperature to around 40°C. A typical flow diagram in the cooling process is shown in Figure 10.3. This system of cooling can be utilized in the following manners:

1. Household refrigerator

This is a practical method for small volume of milk (say from 1 or 2 animals, approx. 5 liters), where the farmers have a refrigerator. The milk in metal container immediately after milking is placed in a domestic household refrigerator, where the milk will slowly cool to the temperature of the refrigerator.

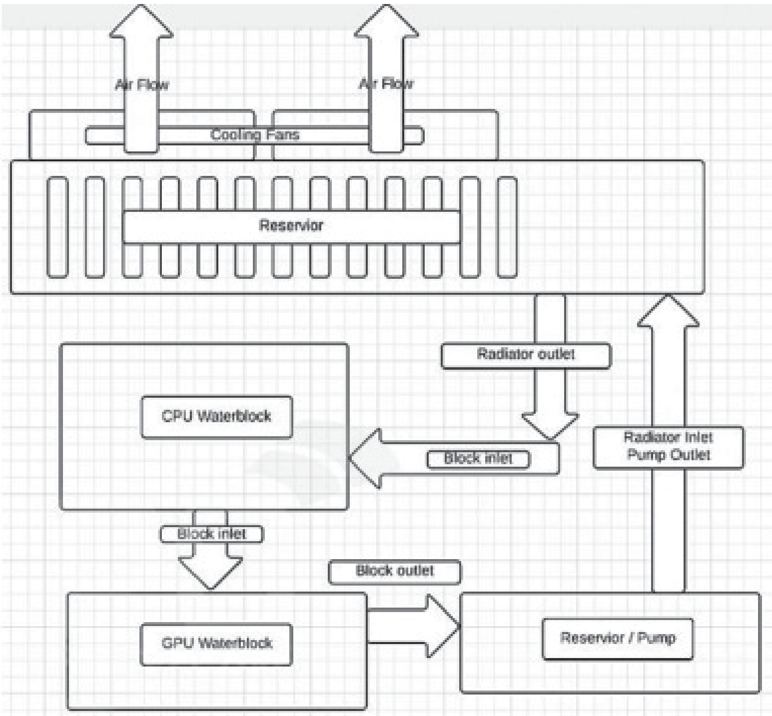

FIGURE 10.3 A typical flow diagram for a cooling system.

2. Surface/immersion cooler

Under direct expansion system, a mechanical refrigerator compressor and condenser (usually air cooled) produces a liquid refrigerant (Freon or ammonia). The liquid refrigerant while passing through an expansion system causes a rapid reduction in temperature [1]. Evaporating unit of a refrigeration unit is submerged directly into cans. Evaporator coil is fitted with an agitator. Milk is agitated for quick and proper transfer of heat from milk to refrigerant.

3. Cabinet cooler

It has a series of surface coolers installed closely together in a vertical position. Capacity of cabinet cooler to cool the milk depends upon the number of sections in surface coolers. This type of cooler requires very small floor space for installation.

10.4.12 EXPANSION BULK TANK

Direct expansion bulk tank, ranging in size from 500 L to 20,000 L, is an energy efficient system of cooling the milk to 40° C within the acceptable period of 4 hours. It is used directly on farms where, medium to large sized herds are milked or at collection/chilling center.

10.4.13 ICE AROUND METAL CANS OF MILK

It is the simplest form of cooling milk, in which ice slabs are stacked around the metal cans of milk on the delivery vehicle and the system relies on heat transfer by contact.

10.4.14 ICE BANK

The ice bank is a widely used for fast cooling of milk. This method of cooling reduces the size of the refrigeration compressor (hence, power requirement) by building up a reserve of ice over a long period. In ice bank, cooling is done through a plate heat exchanger or a surface type cooler with chilled water being the cooling medium. The chilled water is pumped from the ice bank through the heat exchanger and back to the ice bank. Ice banks have considerable flexibility in size and range from a small, self-contained portable unit to a large, using a multiple ammonia compressors, water condensers and associated cooling towers.

10.4.15 INTERNAL TUBULAR COOLER

It is a continuous cooling system consisting of a stainless steel tube of about 2.5–5.0 cm in diameter surrounded by a similar tube, forming a concentric cylinder. Several such tubes may then be connected in series to obtain sufficient cooling. The cooling medium flows in a counter current to the milk flow.

10.4.16 VAT/TANK COOLING

It is suitable for batch cooling, especially of small quantity. It consists of a tank within the tank, with the space between the two being used for circulation of the cooling medium, by either pump or main pressure. An agitator is provided to agitate the milk for rapid cooling.

10.5 CONCLUSIONS

Production of milk is vary widely scattered and at vast distances from the places of high consumptions or processing plant. The hygienic conditions and environment of milk production are still not up to the desired slandered. High ambient temperature throughout the year is an additional disadvantage since the bacterial growth is very rapid in the temperature of milk, as produced, is not brought down immediately after production. Absence of cooling or delayed cooling of milk after production increases the bacterial load considerably. Besides, bacterial multiplication is quite rapid as temperature of storage increases from 4° to 35°C. Therefore, it is essential to cool immediately after milking to maintain quality of milk, as cooling and transporting in bulk to processing plant may take 8 hours or more from time of milking. This stage of cooling/chilling the milk at the production center is most important factor.

10.6 SUMMARY

The dairy industry as it stands today, needs to improve the overall quality of the milk. The bacterial load is a reflection of the hygienic quality of milk. This aspect has certainly been ignored due to lack of facility for proper on-farm cooling of milk immediately after milking. During summer, the high ambient temperature result in high bacterial growth. As the battle for quality is won or lost at the village level itself, it is crucial to control the bacterial growth at the initial stages by cooling immediately after milking. Generally during summer season, cooling of raw and process milk is very important. Now-a-days, several methods and equipment are used such as: can immersion, surface cooler, ice cooling, plate heat exchanger, and rotor freeze.

KEYWORDS

- **bacterial load**
- **brine cooling**
- **bulk milk coolers**
- **cabinet cooler**
- **chilling**
- **cooling equipment**
- **cooling of milk**
- **holding period**
- **hygienic quality of the milk**
- **ice bank**
- **immersion cooler**
- **internal tubular cooler**
- **on-farm cooling**
- **plate heat exchanger**
- **processing period**
- **raw milk**
- **rotor freeze**
- **storage of milk**

REFERENCES

1. Ahmad, T. (2008). *Dairy Plant Engineering and Management*. 8th Edition, Kitab Mahal, 22-A, Sarojini Naidu Marg, Allahabad, India. pp. 189–190.
2. Bidii, K. P. (2015). Factors influencing sustainability of small scale dairy farming: a case of small scale dairy farmers in Cherangany, sub-county, Transnzoia county, Kenya. PhD dissertation, University of Nairobi, Kenya.
3. Holt, C. (2004). An equilibrium thermodynamic model of the sequestration of calcium phosphate by casein micelles and its application to the calculation of the partition of salts in milk. *European Biophysics Journal*, *33*(5), 421–434.
4. http://www.agrimoon.com/wp-content/uploads/Market-Milk-1.0.pdf.
5. http://dairy-technology.blogspot.in/2014/01/chilling-of-milk.html.
6. http://ecoursesonline.iasri.res.in/mod/page/view.php?id=147886.
7. *Tetra Pack: Hand Book of Dairy Processing*. S-221, 86 Lund, Swedan.
8. Walstra, P. (2005). *Dairy Science and Technology*. 2nd Edition, CRC Press, Taylor and Francis Group. pp. 601–603.

APPENDIX A COOLING METHODS

Milkcooling tank

Travel plastic ice cooler

PART III

ENERGY USE IN DAIRY ENGINEERING: SOURCES, CONSERVATION, AND REQUIREMENTS

CHAPTER 11

USE OF RENEWABLE ENERGY IN THE DAIRY INDUSTRY

JANAKKUMAR B. UPADHYAY and RUCHI PATEL

CONTENTS

11.1 INTRODUCTION

Energy is one of the most important resources to sustain our lives and plays an important role in the growth and development of any economy. The requirement is increasing with increase in the population of the world. There is direct correlation between the development and amount of energy used. The demand for energy is increasing every day due to change in life-style of the people. The demand of energy continuously increasing but supply is limited. This situation is called energy crisis [10].

Energy is an essential input for industrial activities. Energy consumed in dairy's operations is in two major forms: Thermal energy and Electrical. Thermal energy consumption in the form of steam is far greater than the consumption of electrical energy in the form of power. Moreover, the quantum and manner in which steam is consumed, in most cases has direct relationship with the quantity of power consumed. To overcome problem the use of renewable energy has great scope for its commercial use in the dairy processing operations and it is estimated that renewable energy could contribute to at least half of all electric power in each of the large economies by 2050. At current rate of consumption and production, coal reserves in India would last for about 130 years and at current rate of consumption and production, oil in India would last only for about 20 to 25 years [4]. The world's average energy consumption per person is equivalent to 2.2 tons of coal. In industrialized countries, it is four times more than the world average energy consumption [7].

This chapter presents an overview of use of renewable energy in the dairy industry

11.2 ENERGY SCENARIO IN INDIA

The energy consumption in India is fourth biggest after China, USA and Russia [22]. The total primary energy consumption from coal (55%), Natural gas (10%), Diesel (1%), Nuclear (3%), Hydro (20%) and renewable (11%) [11]. About 70% of India's electricity generation capacity is from fossil fuels, with coal accounting for 40% followed by crude oil and natural gas at 28% and 6% respectively [24]. For oil and gas, India will become ever more dependent on imports from a few distant part of the world. Today, major electricity generation takes place at central power stations which utilize coal, oil, water, gas or fossil nuclear materials as primary fuel sources. They are not renewable, less efficient (65–75%) and expensive. Renewable energy is that energy which comes from the natural energy flows on earth. Unlike conventional forms of energy, renewable energy will not get exhausted. Renewable energy is also termed as "green energy," "clean energy," "sustainable energy" and "alternative energy" [6].

11.3 CLASSIFICATION OF ENERGY

11.3.1 PRIMARY AND SECONDARY ENERGY

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity.

Primary energy sources are mostly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Primary energy can also be used directly. Some energy sources have non-energy uses, for example coal or natural gas can be used as a feedstock in fertilizer plants.

11.3.2 COMMERCIAL ENERGY AND NON-COMMERCIAL ENERGY

11.3.2.1 Commercial Energy

The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population. Examples: Electricity, lignite, coal, oil, natural gas, etc.

11.3.2.2 Non-Commercial Energy

The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households.

11.4 RENEWABLE AND NON-RENEWABLE ENERGY

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power. The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.

Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

11.4.1 WHAT IS RENEWABLE ENERGY?

Renewable energy is one of the cleanest sources of energy options with almost no pollution or carbon emissions and has the potential to significantly reduce reliance on coal and other fossil fuels. By expanding renewable energy, world can improve air quality, reduce global warming emissions, create new industries and jobs, and move world towards a cleaner, safer, and affordable energy future.

Renewable energy is an energy obtained from natural and persistent flows of energy occurring in the immediate environment [30].

Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power.

11.5 RENEWABLE ENERGY IN INDIA

India has a vast supply of renewable energy resources, and it has one of the largest programs in the world for deploying renewable energy products and systems. According to the Ministry of New and Renewable Energy (MNRE), a renewable energy system converts the energy found in sunlight, wind, falling water, sea waves, geothermal heat or biomass into a form, we can use such as heat or electricity. Among these, the largest share is 70% from wind power, 14% small hydropower, 2% from solar, and 14% from biomass and waste. [11].

11.5.1 WIND ENERGY

Wind energy is basically harnessing of wind power to produce electricity. The kinetic energy of the wind is converted to electrical. When solar radiation enters the earth's atmosphere, different regions of the atmosphere are heated to different degrees because of earth curvature. This heating is higher at the equator and lowest at the poles. Since air tends to flow from warmer to cooler regions, this causes winds, and it is harnessed in windmills and wind turbines to produce power.

Wind power is not a new development as this power, in the form of traditional windmills for grinding corn, pumping water, sailing ships have been used for centuries. Now, wind power is harnessed to generate electricity in a larger scale with better technology.

11.5.1.1 Wind Energy Technology

The basic wind energy conversion device is the wind turbine. Although various designs and configurations exist, these turbines are generally grouped into two types:

1. **Vertical-axis wind turbines**, in which the axis of rotation is vertical with respect to the ground (and roughly perpendicular to the wind stream),
2. **Horizontal-axis turbines**, in which the axis of rotation is horizontal with respect to the ground (and roughly parallel to the wind stream.)

The subsystems include a blade or rotor, which converts the energy in the wind to rotational shaft energy; a drive train, usually including a gearbox and a generator, a tower that supports the rotor and drive train, and other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.

- A wind energy system usually requires an average annual wind speed of at least 15 km/h.

- Small wind turbines can range in size from 20 watts to 100 kilowatts (kW).
- A 60 to 120-foot tower (5 to 10 stories) is common for small wind energy systems.
- The Amount of energy which the wind transfer to rotor depends on the air, rotor area and wind speed.

$$\text{Wind Power} = P = 0.5 \times A \times \rho \times V^3 \tag{1}$$

where, P = power, A = rotor area (m^2), ρ = air density (kg/m^3), and V = wind velocity (m/s).

11.5.1.2 Wind Energy in India

India has 19051 MW of installed capacity and has a potential of utilization up to 102772 MW. Some of the major wind energy plants are located in Tamil Nadu (7160 MW), Gujarat (3093 MW) and Maharashtra (2976 MW) [9].

11.5.2 SOLAR ENERGY

India being situated between the tropic of cancer and the equator, has an average temperature of 25–27.5°C and receives 260–300 clear sunny days per year making it the best solar resource in the world [18]. Earth receives on an average of 5–7 kWh (kilowatt-hour) solar radiation per square meter per day. The sun provides a virtually unlimited supply of energy. The energy from the sun is virtually free once the initial cost of the system has been recovered. The use of solar energy can, not only bridge the gap between the demand and supply of electricity but it also displaces conventional energy, which usually results in a proportional decrease in GHG emissions.

11.5.2.1 Solar Energy in India

The highest annual solar radiation is received by Rajasthan whereas the north-eastern parts of the country receive the least [17]. India has an installed power capacity of 1686 MW, making it sixth largest consumer in the world. Major plants are located in Gujarat, Rajasthan, Jodhpur, Tamil Nadu and Orissa [9].

11.5.2.2 Solar Water Heaters

SWH Systems for industrial and commercial applications are better known by the type of solar collector used. Based on the type of collectors, SWHS are divided into following three types:

- Flat Plate Collectors (FPC);
- Evacuated Tube Collectors (ETC); and
- Solar Concentrator.

11.5.2.3 Flat Plate Collector

A black absorbing surface (absorber) inside the flat plate collectors absorb solar radiation and transfer the energy to water flowing through it. The solar radiation is absorbed by flat plate collectors, which consist of an insulated outer metallic box covered on the top with glass sheet. Inside there are blackened metallic absorber (selectively coated) sheets with built in channels or riser tubes to carry water. The absorber absorbs the solar radiation and transfers the heat to the flowing water. It heats the fluid up to a 40–60°C.

11.5.2.4 Evacuated Tube Collector

The collector is made of double layer borosilicate glass tubes evacuated for providing insulation. The outer wall of the inner tube is coated with selective absorbing material. This helps absorption of solar radiation and transfers the heat to the water, which flows through the inner tube. ETC is highly efficient with excellent absorption (>93%) and minimum emittance (<6%) as the tubes are round and sunrays are striking the tubes at right angles thus minimizing reflection. The entire system is controlled and monitored by an automatic control panel. There is no scaling in the glass tubes thus, suitable for areas with hard water.

11.5.2.5 Solar Concentrator

Solar Concentrator is a device, which concentrates the solar energy incident over a large surface onto a smaller surface. The concentration is achieved by the use of suitable reflecting or refracting elements, which results in an increased flux density on the absorber surface as compared to that existing on the concentrator aperture. In order to get a maximum concentration, an arrangement for tracking the sun's virtual motion and accurate focusing device is required. Thus, a solar concentrator consists of a focusing device, a receiver system and a tracking arrangement. High temperature can be achieved using solar concentrators, and hence they have potential applications in both thermal and photovoltaic utilization of solar energy at high delivery temperatures.

11.5.2.6 Solar Photovoltaic (PV)

Photovoltaic is the technical term for solar electric. Photo means "light" and voltaic means "electric". PV cells are usually made of silicon, an element that naturally releases electrons when exposed to light. Amount of electrons released from silicon cells depend upon intensity of light incident on it. The silicon cell is covered with a grid of metal that directs the electrons to flow in a path to create an electric current. This current is guided into a wire that is connected to a battery or DC appliance. Typically, one cell produces about 1.5 watts of power. Individual cells are connected together to form a solar panel or module, capable of producing 3 to 110 Watts power. Panels can be connected together in series and parallel to make a solar array, which can produce any amount of Wattage as space will allow. Modules are usually designed to supply electricity at 12 Volts. PV modules are rated by their peak Watt output at solar noon on a clear day.

11.5.3 BIO-ENERGY

One third contributor of energy to India is biomass which comprises of solid biomass, which is an organic, non-fossil material of biological origins. Biogas which is principally methane and carbon dioxide is produced by anaerobic digestion of biomass and combusted to produce heat. Biogas is a clean and efficient fuel, generated from cow-dung, human waste or any kind of biological materials derived through anaerobic fermentation process. The biogas consists of 60% methane with rest mainly carbon-dioxide. Biogas is a safe fuel for cooking and lighting. By-product is usable as high-grade manure.

11.5.3.1 Components of Typical Biogas Plant

A digester in which the slurry (dung mixed with water) is fermented, an inlet tank for mixing the feed and letting it into the digester, gas holder/dome in which the generated gas is collected, outlet tank to remove the spent slurry, distribution pipeline(s) to transport the gas into the kitchen, and a manure pit, where the spent slurry is stored. Biomass fuels account for about one-third of the total fuel used in the country. It is the most important fuel used in over 90% of the rural households and about 15% of the urban households. Using only local resources, namely cattle waste and other organic wastes, energy and manure are derived. Thus the biogas plants are the cheap sources of energy in rural areas.

Currently, India has 3697 MW installed capacity and it results in a saving of about Rs. 20,000 crores every year [11]. Following is a list of some states with most potential for biomass production: Andhra Pradesh (200 MW), Bihar (200 MW), Gujarat (200 MW), Karnataka (300 MW), Maharashtra (1,000 MW), Punjab (150 MW), Tamil Nadu (350 MW), Uttar Pradesh (1,000 MW) [9].

11.5.4 HYDRO ENERGY

Energy from small hydro is the oldest. It is most reliable of all renewable energy sources. The potential energy of falling water, captured and converted to mechanical energy by waterwheels, powered the start of the industrial revolution.

Wherever sufficient head, or change in elevation, could be found, rivers and streams were dammed and mills were built. Water under pressure flows through a turbine causes it to spin. The turbine is connected to a generator, which produces electricity.

Hydroelectric power for large-capacity plants has been estimated to be 148,700 MW. For small plants, a total capacity is 15,384 MW [29]. India utilizes twelve primary hydroelectric power plants: Bihar, Punjab, Uttaranchal, Karnataka, Uttar Pradesh, Sikkim, Jammu and Kashmir, Gujarat, and Andhra Pradesh.

11.5.5 WAVE ENERGY

Sea waves are the result of the concentration of energy from various natural sources like sun, wind, tides, ocean currents, moon, and earth rotation. Waves originate from wind and storms far out to sea and can travel long distances without significant energy loss, and hence power production is much steadier and more predictable. Unlike the wind and solar, power from sea waves continues to be produced round the clock.

Wave energy contains roughly 1000 times the kinetic energy of wind. Hence it allows smaller devices to produce power. Wave energy varies as the square of wave height whereas wind power varies with the cube of air speed. Water being 850 times as dense as air results in much higher power produced from wave averaged over time. Theoretically it is possible to extract 40 MW of power per km of coast where there are gentle waves (say 1 m height) and 1000 MW per km of coast where the wave height is 5 m.

Kinetic energy from waves can be used to power a turbine. As the wave rises into a chamber, the rising water forces the air out of the chamber. The moving air spins a turbine which can turn a generator. When the wave goes down, air flows through the turbine and back into the chamber through doors that are normally closed thus generating power even when wave is receding.

11.5.6 TIDAL ENERGY

Tidal energy is another form of ocean energy. Tides are generated by the combination of the moon and sun's gravitational forces. Greatest effects of tides are in spring when sun and moon combine forces. Bays and inlets amplify the tide. Cycles of low and high tides occur twice a day. When tides come into the shore, they can be trapped in reservoirs behind dams. Then when the tide drops, the water behind the dam can be let out just like in a regular hydroelectric power plant. In order for the tidal energy to be practicable for energy production, the height difference needs to be at least 5 m is needed.

11.5.7 GEOTHERMAL ENERGY

The top most part of the earth is the crust. Below the crust of the earth is a layer called mantle. The top layer of the mantle is a hot liquid rock called magma. The crust of the earth floats on this liquid magma mantle. When magma breaks through the surface of the earth in a volcano, it is called lava.

For every 100 meters you go below ground, the temperature of the rock increases about 3°C. So, at a depth of about 3000 meters below ground, the temperature of the rock would be hot enough to boil water. Deep under the surface, water sometimes makes its way close to the hot rock and turns into boiling hot water or into steam. The hot water can reach temperatures of more than 148°C. When this hot water comes up through a crack in the earth, it is known as hot spring.

Some of the areas have so much steam and hot water that it can be used to generate electricity. Holes are drilled into the ground and pipes lowered into the hot water. The hot steam or water comes up through these pipes from below ground. A geothermal power plant is like in a regular power plant except that no fuel is burned to heat water into steam.

11.6 USE OF RENEWABLE ENERGY IN THE DAIRY INDUSTRY

Renewable energy is one of the most promising and important opportunities for value added products in dairying [23]. The type of renewable energy technology used in dairying depends on the type of energy required, access to the renewable energy sources and the design of the dairy facilities and processes. There are number of renewable energy sources which can easily be integrated in the dairy industry such as solar energy for cooling and heating purpose, bio-energy for process heat for dairy operation, etc.

and this energy can generate power at competitive cost. Adoption of renewable energy sources in dairying can help in reducing hydrocarbon emission.

11.6.1 APPLICATION OF SOLAR ENERGY IN THE DAIRY INDUSTRY

Now, a day technology has been developed in such a way that the solar energy is commercially feasible to collect. The cost of solar energy is static or rather decreasing. Solar energy system as non-convectional sources is being developed for various industrial applications such as heating of water for cleaning, washing, and/or as boiler feed water, etc. Presently, the Indian dairy industry has to bear increased cost of energy/liter of processed milk due to increased cost of traditional energy inputs. So, the use of solar energy in dairy processing operation is the best option to overcome convectional energy sources.

11.6.1.1 Solar Water Heating Systems (SWH)

Solar water heating considered as the most cost-effective alternatives for industry and household application. A dairy unit requires many heating operation which are at present carried out using steam from boiler. Thus, solar energy for various heating application is already being used in some of the dairy plants for reducing fuel bill [32]. A solar water heater (SWH) is a combination of an array of collectors, an energy transfer system and a thermal storage system. In active solar water heating systems, a pump is used to circulate the heat-transferring fluid through the solar collectors. The amount of hot water produced from a SWH critically depends on design and climatic parameters such as solar radiation, ambient temperature and wind speed. SWH system heating water at 60–80°C or even higher temperature which can be conveniently used for crate washing, cleaning, CIP, pre-heating of boiler feed water, etc. [19].

Solar Energy in Pasteurization

There is tremendous scope of utilizing solar energy in dairy processing such as pasteurization of milk. Solar panels/concentrator based milk pasteurizer system is developed to meet the demand of pasteurization. It was observed that base temperature of solar heated water reached up to 100°C, which have easily attained pasteurization temperature ranging from 65–75°C in two-three hours [31].

Solar Steam Generation

Low temperature steam is extensively used in sterilization processes and desalination evaporator supplies. Parabolic trough collectors (PTCs) are high efficient collectors commonly used in high temperature applications to generate steam. PTCs use 3 concepts to generate steam [14] the steam flash, direct and the unfired-boiler. The Heat Transfer fluid that circulates inside the solar field (primary cycle) is heated and transferred to heat exchanger, including super heaters, evaporators and pre heaters, where steam is generated for the power cycle or other applications [1]. This steam can be used for sterilization and pre-heating of air and also in drying operation.

Solar Energy for Cooling Purpose

Photovoltaic Operated Refrigeration Cycle, Photovoltaic (PV) involves the direct conversion of solar radiation to direct current (DC) electricity using semiconducting materials. In concept, the operation of a PV-powered solar refrigeration cycle is simple. Solar photovoltaic panels produce DC electrical power that can be used to operate a dc motor, which is coupled to the compressor of a vapor compression refrigeration system [15]. This system is feasible for cooling of milk in chilling center.

Solar Absorption Refrigeration System (NH_3-Water)

Solar Absorption Refrigeration system was designed to operate with the ammonia water mixture for a maximum capacity of 8 kg of ice/day. It consists of a compound parabolic collector (CPC) with a cylindrical receiver acting as the generator/absorber, a condenser, a storage tank, an expansion valve, a capillary tube and an evaporator. The system operates exclusively with solar energy and no moving parts are required [20]. The Electric heating requires 61 MJ of energy to produce 9 kg of ice and solar energy produces 7–10 kg of ice after receiving 28–30 MJ of radiation energy.

Solar powered Li-Br-water vapor absorption refrigeration (SVAR) system having rated capacity of 5 TR (17.5 kW) is available. The SVAR system consists of array of heat pipe evacuated tube collectors (HP-ETC), generator, evaporator, absorber, condenser and heat exchanger. The HP-ETC produces hot water at a temperature of 65–95°C which is used for the supply of thermal energy at the generator of the system. The values of actual COP of the SVAR system ranged from 0.24 to 0.66. The thermal energy supplied at generator ranged from 31.01 to 60.69 kW. The refrigerating effect is produced by SVAR system is 11.19 to 22.31 kW. The use of solar energy for the operation of VAR has a scope for cold storage of fruits and vegetables where temperature requirement is not very low [13].

Solar Drying and Dehydration Systems

Currently, electricity is always used to heat the air and as an additional energy source. Conventional drying systems using fossil fuels as a source of combustion, while solar dryer use solar irradiation for drying in industries, such as brick, crops, fruits, coffee, wood, textiles, leather, green malt and sewage sludge [25]. There are two main groups of dryer, high and low temperature dryers. Almost all high-temperature dryers use fossil fuels or electricity for the heating process. While the low temperature dryers use fossil fuels or solar energy, a low temperature generated by solar energy is ideal for use in the preheating process [12].

Direct Solar Drying

Direct drying consists of use of incident radiation only, or incident radiation plus reflected radiation. Most solar drying techniques that use only direct solar energy also use some means to reflect additional radiation onto the product to further increase its temperature. An example of direct absorption dryer is the hot box dryer. The aim of this type of a dryer is mainly to improve product quality by reducing contamination by dust, insect infestation, and animal or human interference. It consists of a hot box with a transparent top and blackened interior surfaces. Ventilation holes in the base and upper parts of slide walls maintained a natural air circulation. The farmers can dehydrate vegetables when these are available in plenty and at low cost. Dehydrated vegetables can be sold in the off-season when prices of vegetables are high and farmers can generate more income [21].

Indirect Solar Drying

Indirect solar dryer is generally known as conventional dryer. In this case, a separate unit termed as solar air heater is used for solar energy collection for heating of entering air. The air heater is connected to a separate drying chamber where the product is kept. The heated air is allowed to flow through wet material. Here, the heat for moisture evaporation is provided by convective heat transfer between the hot air and the wet material. The drying is basically by the difference in moisture concentration between the drying air and the air in the vicinity of product surface. A better control over drying is achieved in indirect type of solar drying systems and the product obtained is of good quality [27].

Solar Energy for Pumping Dairy Fluids

An SPV pump is a DC or AC, surface-mounted or submersible or floating pump that runs on power from an SPV array. It may use to run a hot water pump, chill water pump, milk pump and CIP (cleaning in place) pump. The array is mounted on a suitable structure and placed in a shadow free open space with its modules facing south and inclined at local latitude. A typical SPV pumping system consists of an SPV array of 200–3000 W capacity, mounted on a tracking/non-tracking type of structure. The array is connected to a DC or AC pump of matching capacity. SPV pumps are used to draw water for irrigation as well as for drinking. The SPV array converts sunlight into electricity and delivers it to run the motor and pump. The water can be stored in tanks for use during non-sunny hours, if necessary [8].

Solar Energy to Lightning Dairy Offices and Premises

SPV lighting systems are becoming popular in both the rural and urban areas of the country. In rural areas, SPV lighting systems are being used in the form of portable lanterns, home-lighting systems with one or more fixed lamps, and street-lighting systems. A solar street-lighting system (SLS) is an outdoor lighting unit used to illuminate a street or an open area usually in dairy, garden, road approach to dairy and chilling center [8]. A compact fluorescent lamp (CFL) is fixed inside a luminary which is mounted on a pole. The PV module is placed at the top of the pole, and a battery is placed in a box at the base of the pole. The module is mounted facing south, so that it receives solar radiation throughout the day. A typical street-lighting system consists of a PV module of 74 W capacities, a flooded lead–acid battery of 12 V, and a CFL of 11 W rating. The CFL automatically lights up when the surroundings become dark and switches off around sunrise time [6].

Solar Energy for Electrifying (Electric Fences)

Solar Electric fences are widely used in dairy to prevent stock or predators from entering or leaving an enclosed field. These fences usually have one or two 'live' wires that are maintained at about 500 volts DC. These give a painful, but harmless shock to any animal that touches them. This is generally sufficient to prevent stock from pushing them over. They require a high voltage but very little current and they are often located in remote areas where the cost of electric power is high. These requirements can be met by a photovoltaic system involving solar cells, a power conditioner and a battery [5].

11.6.2 APPLICATION OF BIO-GAS IN THE DAIRY INDUSTRY

Currently, most dairy digester produced biogas is used on site for energy generation. Electrical Production is generally the primary use of the produced biogas although heat is frequently also produced for use in the anaerobic digester either as part of a combined heat and power system (CHP) or separate dedicated boiler systems.

11.6.2.1 Biogas As Electricity and Heat Generation

Anaerobic digester systems have been used for decades at municipal wastewater facilities, and more recently, have been used to process industrial and agricultural wastes. These systems are designed to optimize the growth of the methane-forming (methanogenic) bacteria that generate CH_4. Typically, using organic wastes as the major input, the systems produce biogas that contains 55–70% CH_4 and 30–45% CO_2. On dairy farms, the overall process includes the following:

Manure Collection and Handling

Key considerations in the system design include the amount of water and inorganic solids that mix with manure during collection and handling.

Pre-treatment: Collected manure may undergo pre-treatment prior to introduction in an anaerobic digester. Pre-treatment include screening, grit removal, mixing, and/or flow equalization is used to adjust the manure or slurry water content to meet process requirements. A concrete or metal collection/mix tank may be used to accumulate manure, process water and/or flush water. Proper design of a mix tank prior to the digester can limit the introduction of sand and rocks into the anaerobic digester itself. If the digestion processes requires thick manure slurry, a mix tank serves a control point where water can be added to dry manure or dry manure can be added to dilute manure. If the digester is designed to handle manures mixed with flush and process water, the contents of the collection/mix tank can be pumped directly to a solids separator. A variety of solids separators, including static and shaking screens are available and currently used on farms.

Anaerobic digestion: An anaerobic digester is an engineered containment vessel designed to exclude air and promote the growth of methane bacteria. The digester may be a tank, a covered lagoon, or a more complex design, such as a tank provided with internal baffles or with surfaces for attached bacterial growth. It may be designed to heat or mix the organic material. Manure characteristics and collection technique determine the type of anaerobic digestion technology used. Some technologies may include the removal of impurities such as hydrogen sulfide (H_2S), which is highly corrosive.

By-product recovery and effluent use: It is possible to recover digested fiber from the effluent of some dairy manure digesters. This material can then be used for cattle bedding or sold as a soil amendment. Most of the ruminant and hog manure solids that pass through a separator will digest in a covered lagoon, leaving no valuable recoverable by-product.

Biogas recovery: Biogas formed in the anaerobic digester bubbles to the surface and may accumulate beneath a fixed rigid top, a flexible inflatable top, or a floating cover, depending on the type of digester. The collection system, typically plastic piping, then directs the biogas to gas handling subsystems.

Biogas handling: Biogas is usually pumped or compressed to the operating pressure required by specific applications and then metered to the gas use equipment. Prior to this, biogas may be processed to remove moisture, H_2S, and CO_2. Depending on applications, biogas may be stored either before or after processing, at low or high pressures.

Biogas use; Recovered biogas can be used directly as fuel for heating or it can be combusted in an engine to generate electricity. Biogas, a mixture consisting primarily of methane and carbon dioxide, is produced from dairy wastes through anaerobic digestion, a natural process that breaks down organic material in an oxygen-free environment [16].

11.6.2.2 Biogas for Refrigeration

Refrigeration accounts for about 15% to 30% of the energy used on dairy farms; most of this is for compressors used for chilling milk. Since dairy cows are milked daily, a steady source of energy is required for refrigeration needs.

Many dairies use well water for pre-chilling, chilled water or glycol can be produced from biogas-fired absorption or adsorption chillers and used in milk pre-coolers. Milk cooling using absorption and adsorption chillers also presents a potential opportunity to use waste heat captured from a biogas-driven generator set. Use of this waste heat could significantly reduce the on-farm electrical refrigeration load [16].

11.7 SUMMARY

Today, India is number one in milk production, producing about 138 million tons per annum. Out of these approximately 20% of the total milk production is handled by the organized sectors. Most of the milk processing operations, room conditioning for milk product packaging and cold stores for milk and milk products are operating on grid electric supply. Energy is one of the critical inputs for economic development of any Country.

In order to overcome the present energy scenario problems, energy should be conserved and since we are consuming disproportionate amount of energy that day is not far when all our non-renewable resources will expire forcing us to rely just on renewable sources. To overcome this problem, the use of renewable energy mainly solar and bio energy in the dairy is generally found for hot water supply to boiler, and hot water generator for processing of milk or for CIP cleaning. Use of renewable energy has great scope for its commercial use in the dairy processing operations and it is estimated that renewable energy could contribute to about half of all the types of energy used in each of the large economies by 2050.

KEYWORDS

- **anaerobic digestion**
- **bio energy**
- **biogas for electricity and heat generation**
- **biogas recovery**
- **biogas refrigeration**
- **dairy**
- **energy**
- **energy scenario**
- **evacuated tube collectors (ETC)**
- **flat plate collectors (FPC)**
- **geothermal energy**
- **hydro energy**
- **India**
- **non renewable energy**
- **renewable energy**
- **renewable energy in dairy**
- **solar absorption refrigeration system**
- **solar concentrator**
- **solar dryer**

- **solar electric fence**
- **solar energy**
- **solar light**
- **solar pump**
- **solar water heater**
- **tidal energy**
- **wave energy**
- **wind energy**

REFERENCES

1. Alguacila, M., Prietoa, C., Rodriguez, A., & Lohr, A. (2014). Direct steam generation in parabolic trough collectors. *Energy Procedia*, *49*, 21–29.
2. BEE, (2013). Application of non-conventional and renewable energy sources http://www.emea.org/pdf, 147–161.
3. BEE, (2015). Application of non-conventional and renewable energy sources http://www.emea.org/pdf, 263–290.
4. Bhattacharya, T. (2014). Sustained growth of green energy economics. *International Journal of Inventive Engineering and Sciences, 2*, 16–18.
5. Carr, A., Fletcher, S., O'Mara, K., & Rayner, M. (1999). *Solar cell principle and applications*. Australian CRC for renewable energy Ltd.
6. Date, V. (2010). Financial feasibility of solar power project with reference to rural electrification of 39 talukas in Karnataka. NICMR.
7. Desai, H., & Zala, A. (2010). An overview on present energy scenario and scope for energy conservation in dairy industry. *National Seminar on Energy Management and Carbon Trading in Dairy Industry*, pp. 1–7.
8. Desai, D., Rao, J., Patel, S., & Chauhan, I. (2013). Application of solar energy for sustainable dairy development. *European Journal of Sustainable Development*, *4*, 131–140.
9. Dhingra, R., Jain, A., Pandey, A., & Mahajan, S. (2014). Assessment of renewable energy in India. *International Journal of Environmental Science and Development, 5*, 459–462.
10. Garg, P. (2012). Energy scenario and vision 2020 in India. *Journal of Sustainable Energy and Environment*, *3*, 7–17.
11. Gera, R. K., Rai, H. M., Parvej, Y., & Soni, H. (2013). Renewable energy scenario in India: opportunities and challenges. *Indian Journal of Electrical and Biomedical Engineering*, *1*, 10–16.
12. Handayani, N. A., & Ariyanti, D. (2012). Potential of solar energy applications in Indonesia. *Journal of Renewable Energy Development*, *1*, 33–38.

13. Juda, A. (2014). *Performance Evaluation of Solar Powered Vapor Absorption Refrigeration System*. MTech Thesis. Anand Agricultural University, Anand.
14. Kalogirou, S., Lloyd, S., & Ward, J. (1997). Modeling optimization and performance evaluation of a parabolic trough collector steam generation system. *Solar Energy*, *60*, 49–59.
15. Klein, S. A., & Reindl, D. T. (2005). Solar Refrigeration. *American Society of Heating, Refrigerating and Air-Conditioning Engineers*, *47*, 26–30.
16. Krich, K., Augenstein, D., Batmale, J. P., Benemann, J., Rutledge, B., & Salour, D. (2005). *Biomethane from Dairy Waste*. A Sourcebook for the Production and Use of Renewable Natural Gas in California.
17. Md-Aquil, A., Shadab, K., Shadman, H. Q., & Tiwari, G. (2014). The contemporary scenario of Indian renewable energy sector. *International Research Journal of Environment Science, 3*, 82–89.
18. Meisen, P., & Quéneudec, E. (2006). Overview of sustainable renewable energy potential of India. http://www.geni.org/globalenergy/research/renewableenergypotential-ofindia/pdf.
19. Mistry, M., & Gurjar, M. (2010). Application of solar water heater and its feasibility as a CDM project in dairy industry. National Seminar on Energy Management and Carbon Trading in Dairy Industry, pp. 121–123.
20. Moreno-Quintanar, G., Rivera, W., & Best, R. (2011). Development of a solar intermittent refrigeration system for ice production. *World Renewable Energy Congress*.
21. Nahar, N. M. (2009). Processing of vegetables in a solar dryer in arid areas. International Solar Food Processing Conference.
22. Panwar, V., & Kaur, T. (2014). Overview of Renewable Energy Resources of India. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, *3*, 1–9.
23. Rathor, N. S. (2010). Scope of renewable energy sources in dairy industries for energy conservation. National Seminar on Energy Management and Carbon Trading in Dairy Industry, pp. 23–26.
24. Saradhi, I. V., Pandit, G. G., & Puranik, V. D. (2009). Energy supply, demand and environmental analysis – a case study of Indian energy scenario. *International Journal of Civil and Environmental Engineering, 1*, 115–120.
25. Schnitzer, H., Christoph, B., & Gwehenberger, G. (2007). Minimizing greenhouse gas emissions through the application of solar thermal energy in industrial processes, approaching zero emissions. *Journal of Cleaner Production*, *15*, 71–86.
26. Sharma, A., Chen, C. R., & Vu Lan, N. (2009). Solar-energy drying systems: A review. *Renewable and Sustainable Energy Reviews*, *13*, 1185–1210.
27. Sontakkel, M. S., & Salve, S. P. (2015). Solar drying technologies: A review. *International Refereed Journal of Engineering and Science*, *4*, 29–35.
28. State-wise potential of various renewable energy technologies, (2013). http://data.gov.in/sites/default/files/Statewise_Potential_of_Various_Renewable_Energy_T echnologies_1.xls.
29. Sukhatme, S. P. (2012). Can India's future needs of electricity be met by renewable energy sources? A revised assessment. *Current Science*, *103*, 79–86.
30. Twidell, J., & Weir, T. (2006). *Renewable Energy Resources*. Second edition, Taylor and Francis, 2 Park Square, Milton Park, Abingdon.

31. Zahira, R., Akif, H., Amin, N., Azam, M., & Haq, Z. (2009). Fabrication and performance study of a solar milk pasteurizer. *Pakistan Journal of Agricultural Science, 46*, 162–170.
32. Zala, A. M., Shah, D. R., & Birendrakumar (2007). Advancement in utilities in dairy plants. National seminar on revamping dairy engineering: education and industry in global context.
33. www.anaerobic-digestion.com.
34. www.mospi.gov.in (2015). *A Report on Energy Statistics*. Ministry of Statistics And Program Implementation Overnight of India, New Delhi.
33. www.nddb.org (2015). Dairy Plant Management Training Program Report. 16th Feb–20th March, 2015, NDDB, Anand.
34. www.suscon.org/cowpower/biomethaneSourcebook/Chapter_1.pdf.
35. www.usdairy.com/~/media/usd/public/dairypowercasestudy_renewableenergy.pdf.
36. www.uvka.net/static/Downloadable/Vasudara-Dairy-Profile.pdf.

CHAPTER 12

MINIMIZING POWER REQUIREMENT FOR PUMPS IN DAIRY INDUSTRY

ADARSH M. KALLA, BHAVESH B. CHAVHAN, P. BISEN, and C. SAHU

CONTENTS

12.1 INTRODUCTION

The dairy industry faces an increasingly competitive environment, and looks out opportunities to reduce production costs without negatively affecting the yield or the quality of the finished product. The challenge of maintaining high product quality, while simultaneously reducing production costs, can often be met through investments in energy efficiency, which can include the purchase of energy-efficient technologies and the implementation of plant-wide energy efficiency practices. Energy-efficient technologies can often offer additional benefits, such as quality improvement and can often lead to reductions in emissions of greenhouse gasses and other important air pollutants. Investments in energy efficiency are therefore a sound business strategy in today's manufacturing environment. The cost of electrical energy is increasing dramatically and awareness of energy consumption in the dairy industry is becoming an issue in the cost of milk production. Hence, measures have to be taken to reduce electricity consumption wherever it is possible.

According to IEA [7], electricity cost is one of the major factors which influence the firm's decisions and growth of the industries. In most developed countries, industrial users pay lower prices for electricity compared to other users because the cost of supplying electricity to industrial users is typically lower [7]. However, in India, industrial users pay higher price for electricity relative to domestic and agricultural users. Politicians desire to win favor with households and farmers who form crucial voting blocks. For instance in 2000, industrial users in India paid about 15 times the price paid by agricultural users for electricity [1]. In a 2006 World Bank survey, Indian manufacturing firms were asked to indicate which element posed the biggest constraint to their operations out of a list of 15 elements including electricity, access to finance, and corruption. Electricity was the most common major obstacle indicated, with more than 36 percent of firms listing electricity as the biggest constraint [6].

Pumping systems account for nearly 20% of the world's energy used by electric motors and 25% to 50% of the total electrical energy usage in certain industrial facilities [11]. Hence it makes us necessary to take prerequisite steps to reduce power consumption in pumps. In dairy industry different types of pumps are used based on their function and type of the product to be pumped. Basically pumps are classified into two types: dynamic pumps and positive displacement pumps.

This chapter introduces types of pumps that are used in the dairy industry.

12.2 POSITIVE DISPLACEMENT PUMPS

They are distinguished by the way they operate. The liquid is taken from one end and positively discharged at the other end for every revolution (Figure 12.1). Positive displacement pumps are widely used for pumping mostly viscous fluids, such as cream with high fat content, cultured milk products, curd, whey, etc.

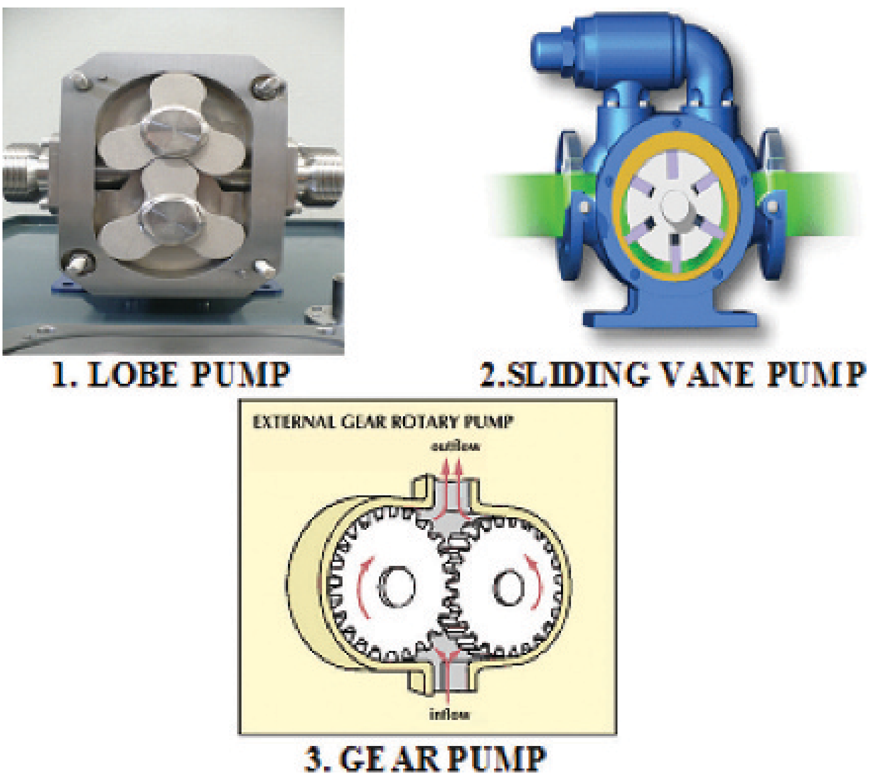

FIGURE 12.1 Types of pumps.

- Reciprocating pumps: If the displacement is by reciprocation of a piston plunger, then it is called as reciprocating pump. Reciprocating pumps are used only for pumping viscous liquids and oil wells.
- Rotary pumps: If the displacement is by rotary action of a gear or vanes in a chamber of diaphragm in a fixed casing then it is called as rotary pump. In dairy industry, rotary pumps are used to pump cream and other viscous products.

12.3 DYNAMIC PUMPS

In the centrifugal pump, liquid enters the eye of the impeller and exits the impeller due to the centrifugal force (Figure 12.2). As water leaves the eye of the impeller, a low-pressure area is created, causing more water to flow into the eye (Atmospheric pressure and centrifugal force causes this to happen). Velocity is developed by the spinning impeller, and water velocity is collected by the diffuser and converted into the pressure by specially designed pathway [2].

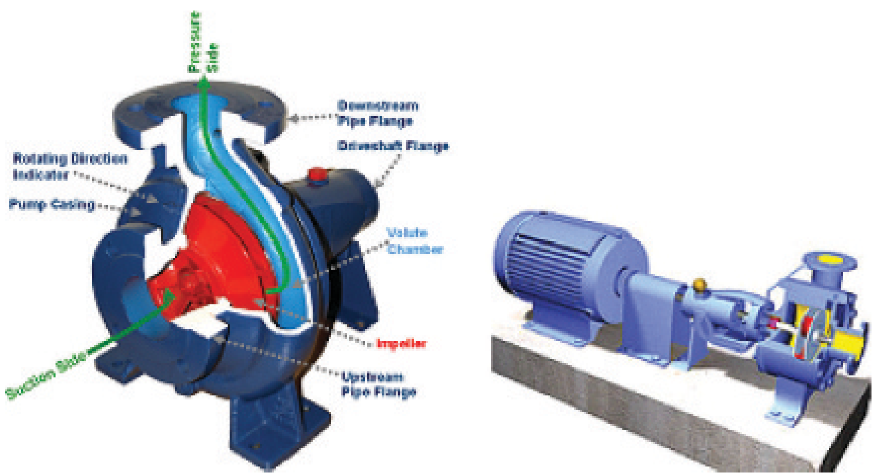

FIGURE 12.2 Centrifugal pump.

12.4 SANITARY PUMPS

One striking difference between Indian and the western dairy processing has been the type of pumps used in the plants. While most of the dairies in India use sanitary centrifugal pumps almost exclusively, dairies in the western countries use a wide range of positive displacement pumps mainly bilobe and trilobe, rotary cam and twin-screw designs. Many leading equipment companies offer a big selection of such pumps with different capacities and different rotor designs and different materials to suit different applications. Also, these rotary pumps offer options such as horizontal and vertical porting. Vertical porting has self-draining and venting capacity while horizontal porting facilities suction of high viscosity products. Use of these pumps allows metering of the fluid while pumping, which makes the automation possible.

Centrifugal pumps are also used where a large capacity is required like receiving and transferring. Sanitary centrifugal pumps designs include standard centrifugal pump, high pressure pump which can work at an inlet pressure of up to 40 kg/cm^2 and are suitable for reverse osmosis and ultra-filtration; and multistage pumps for low capacity and high pressure applications. The present trend is to use frequency converters on these motors to have these pumps operate at variable capacities as per processing needs. Usually the output of centrifugal pump is reduced by throttling the flow in the discharge side but this occurs at the increased pressure drops. Frequency converters on the other hand shift the operating point of the centrifugal pump by changing its speed, while keeping the pressure drop the same.

Many designs of such pumps are used for feeding the packaging machine lines, and balance tank feed pump while maintaining a predetermined level of pressure. Another design of centrifugal pump features a helical screw which helps feed liquids into the eye of the impeller which has specific application for pumping hot water under vacuum as they reduce the net positive suction head and reduce cavitation problems.

12.5 ENERGY EFFICIENCY FOR PUMP SYSTEMS

The basic components in a pump system are pumps, drive motors, piping networks, valves, and system controls. Some of the most significant energy efficiency measures applicable to these components and to pump systems as a whole are described below.

12.5.1 PUMP SYSTEM MAINTENANCE

In a typical life cycle cost, energy and maintenance costs will account for over 50–95% of pump ownership costs with initial costs less than 15% of pump life cycle costs. Hence maintenance of pump plays a major role in energy efficient pumping system [12].

The improper maintenance of pump lowers the system efficiency and causes pumps to wear out more quickly, and increases pumping energy costs. The implementation of a pump system maintenance program will help to avoid these problems by keeping pumps running optimally. Furthermore, improved pump system maintenance can lead to pump system energy savings of anywhere from 2 to 7% [13]. A solid pump system maintenance program will generally include the following tasks:

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, on an annual or semiannual basis.
- Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between 2 to 60 drops per minute.
- Inspection and replacement of mechanical seals. Allowable leakage is typically 1 to 4 drops per minute.
- Wear ring and impeller replacement. Pump efficiency degrades by 1 to 6% for impellers less than the maximum diameter and with increased wear ring clearances.
- Checking of pump/motor alignment.
- Inspection of motor condition, including the motor winding insulation.

12.5.2 PUMP SYSTEM MONITORING

Monitoring can be used in combination with a proper maintenance program to detect pump system problems before they cause major performance issues or equipment repairs. Monitoring can be done manually on a periodic basis (e.g., performing regular bearing oil analyzes to detect bearing wear or using infrared scanning to detect excessive pump heat) or can be performed continuously using sensor networks and data analysis software (e.g., using accelerometers to detect abnormal system vibrations) [9]. Monitoring can help to keep pump systems running efficiently by detecting system blockages, impeller damage, inadequate suction, clogged or gas-filled pumps or pipes, pump wear, and if pump clearances need to be adjusted. In general, a good pump monitoring program should include the following aspects:

- Wear monitoring.
- Vibration analysis.
- Pressure and flow monitoring.
- Current or power monitoring.
- Monitoring of differential head and temperature rise across pumps (also known as thermodynamic monitoring).
- Distribution system inspection for scaling or contaminant build-up.

12.6 DIAGNOSTIC TOOLS

The pumps are monitored for their efficient working condition by using different diagnostic tools. The tools keep a check on the pump by using different analyzers. The analyzers are capable of detecting the changes in temperature and sound patterns, occurring in the pump which is considered to be harmful.

- **Thermography** – An infrared thermometer allows for an accurate, non-contact assessment of temperature. Its application for pumps includes assessments on bearing assemblies at the impeller housing and motor system connections.
- **Ultrasonic analyzer** – Fluid pumping systems emit very distinct sound patterns around bearings and impellers. In most cases, these sounds are not audible to the unaided ear, or are drown-out by other

equipment noises. Using an ultrasonic detector, the analyst is able to isolate the frequency of sound being emitted by the bearing or impeller. Changes in these ultrasonic wave emissions are indicative of changes in equipment condition-some of these changes can be a precursor to component degradation and failure.

- **Vibration analyzer** – Within a fluid pump, there are many moving parts; some in rotational motion and some in linear motion. In either case, these parts generate a distinct pattern and level of vibration. Using a vibration analyzer, the analyst can discern the vibration amplitude of the point on the equipment being monitored. This amplitude is then compared with trended readings. Changes in these readings are indicative of changes in equipment condition [10].

12.7 HIGH-EFFICIENCY PUMPS

Considering that a pump's efficiency may degrade by 10–25% over the course of its life, the replacement of aging pumps can lead to significant energy savings [12]. The installation of newer, high-efficiency pumps typically leads to pump system energy savings of 2–10% [4].

A number of high-efficiency pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both operating costs and capital costs. For a given duty, selecting a pump that runs at the highest speed suitable for the application will generally result in a more efficient selection as well as the lowest initial cost.

12.8 CONTROL SYSTEMS

Control systems can increase the energy efficiency of a pump system by shutting off pumps automatically when demand is reduced, or, alternatively, by putting pumps on standby at reduced loads until demand increases.

In 2000, Cisco Systems upgraded the controls on its fountain pumps so that pumps would be turned off automatically during periods of peak electrical system demand. A wireless control system was able to control all pumps simultaneously from one location. The project saved $32,000 and 400,000 kWh annually, representing a savings of 61.5% in the total energy consumption of the fountain pumps [3]. With a total cost of $29,000, the simple payback period was 11 months. In addition to energy savings, the project reduced maintenance costs and increased the pump system's equipment life.

12.9 PROPERLY SIZED PIPES

Pipes that have a smaller diameter size for a required velocity will require higher amount of energy for pumping. In much the same way that drinking a beverage through a small straw requires a greater amount of suction. Hence where ever it is possible, the pipe diameters can be increased to reduce pumping energy requirements, but the energy savings due to increased pipe diameters must be balanced with increased costs for piping system components. Increasing pipe diameters will only be cost effective during greater pump system retrofit projects. It has been estimated that an energy savings of 5% to 20% can be obtained by proper pipe sizing [13].

12.10 PUMP SELECTION

The pump is selected based on how best the system curve supplied by the user and pump curve intersects, when graphically superimposed on each other. The point at which system curve and pump curve intersect is called as the pump operating point or best efficiency point. At this point the pump operates at its high speed and gives best output (Figure 12.3). However, it is impossible for one operating point to meet all desired operating conditions.

The right selection of pump depends on operating point and how accurate the system curve is calculated. If actual calculated system curve is different from that calculated, the pump will operate at a flow and head different to that expected. Generally, in industries, to have an additional safety margins to the calculated system curve, the facility manager will sufficiently select a large sized pump that results in installing an oversized pump, which will operate at an excessive flow rate, which increase energy usage and reduce pump life.

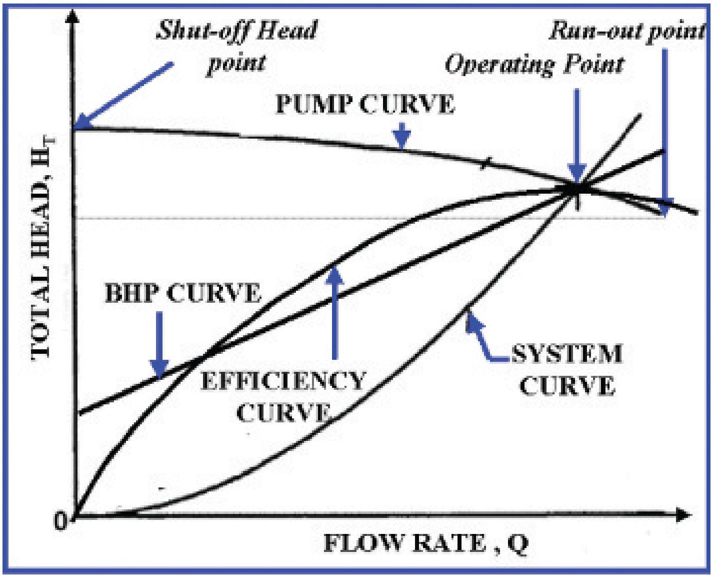

FIGURE 12.3 Pump operating point.

12.11 SELECTION OF PROPERLY SIZED PUMPS

Pumps that are oversized for a particular application consume more energy than is truly necessary. Replacing oversized pumps with pumps that are properly sized can often reduce the electricity use of a pumping system by 15–25% [13]. If a pump is dramatically oversized, often its speed can be reduced with gear or belt drives or a slower speed motor. The typical payback period for these strategies can be less than one year [5].

The efficiency of a pump is affected when the selected pump is oversized. This is because flow of oversized pumps must be controlled with different methods, such as a throttle valve or a bypass line. These devices provide additional resistance by increasing the friction. As a result the system curve shifts and intersects the pump curve at a different point, a point of lower efficiency (Figure 12.3). In other words, the pump efficiency is reduced because the output flow is reduced but not the power consumption. The inefficiency of oversized pumps can be overcome by, for example, the installation of variable speed drives, operating the pump at a lower rpm, or installing a smaller impeller or trimmed impeller.

The energy usage in a pumping installation is determined by the flow required, the height lifted and the length and friction characteristics of the pipeline. The power required to drive a pump (P_i), is defined as follows:

$$P_i = [\rho\ g\ H\ Q]/E \qquad (1)$$

where, P_i is the input power required (W); ρ is the fluid density (kg/m^3); g is the standard acceleration of gravity (= 9.81 m/s^2); H is the energy Head added to the flow (m); Q is the flow rate (m^3/s); and E is the efficiency of the pump plant in decimals.

The energy head added by the pump (H) is a sum of the static lift, the head loss due to friction and any losses due to valves or pipe bends all expressed in meters of fluid. Power is more commonly expressed in kilowatts (10^3 W, kW) or horsepower (1.00 kW = hp/0.746). The value for the pump efficiency (E) may be stated for the pump itself or as a combined efficiency of the pump and motor system. The *energy usage* is determined by multiplying the power requirement by the length of time the pump is operating.

12.12 AVOIDING THROTTLING VALVES AND BYPASS CONTROLS

As discussed earlier, inaccurate calculation of system curve will lead to selection of oversized pumps which has excessive flow rate and increased head. To overcome these problems industries started using throttling valve and bypass control loop. Throttling valves and bypass loops are indications of oversized pumps as well as the inability of the pump system design to accommodate load variations efficiently, and should always be avoided [8].

However throttling valve reduces the flow, it does not reduce the power consumed, as the total head (static head) increases. This method increases vibration and corrosion and thereby increases maintenance costs of pumps and potentially reduces their lifetimes.

The flow can also be reduced by installing a bypass control system, in which the discharge of the pump is divided into two flows going into two separate pipelines. One of the pipelines delivers the fluid to the delivery point, while the second pipeline returns the fluid to the source. In other words, part of the fluid is pumped around for no reason, and thus is energy inefficient. Because of this inefficiency, this option should therefore be avoided. The elimination of bypass loops and other unnecessary flows can also lead to energy savings of 10–20% [13]. But in some cases, small bypass line is required to prevent a pump running at zero flow required for safe operation of pump.

12.13 IMPELLER TRIMMING

Impeller trimming is one of the methods to reduce the pump flow rate. Impeller trimming refers to the process of reducing an impeller's diameter, so that it matches to the required flow rate and hence reducing the energy added by the pump to the system fluid. Changing the impeller diameter gives a proportional change in peripheral velocity, which in turn directly lowers the amount of energy imparted to the system.

According to affinity law, the equations relating pump performance parameters and impeller diameter are given as follows (Figure 12.4):

$$Q \alpha D$$

$$H \alpha D^2$$

$$P \alpha D^3 \tag{2}$$

Hence from Eq. (2), it is clear that power consumed is directly proportional to cube of diameter. The small change in diameter can reduce power consumption greatly.

According to the U.S. DOE [9], one should consider trimming an impeller when any of the following conditions occur:

- Many system bypass valves are open, indicating that excess flow is available to system equipment.
- Excessive throttling is needed to control flow through the system or process.
- High levels of noise or vibration indicate excessive flow.
- A pump is operating far from its design point.

Trimming an impeller is slightly less effective than buying a smaller impeller from the pump manufacturer, but it can be useful when an impeller at the next smaller available size would be too small for the given pump load. Changing the impeller diameter is an energy efficient way to control the pump flow rate. However, for this option, the followings should be considered:

- This option cannot be used where varying flow patterns exist.
- The impeller should not be trimmed more than 25% of the original impeller size, otherwise it will cause cavitation producing vibrations and resulting in decrease of the pump efficiency.
- The balance of the pump has to been maintained, for example, the impeller trimming should be the same on all sides.

In Figures 12.4 and 12.5, one can observe that after trimming the impeller the pump serves at lower flow rate and head, which once operated at higher flow rate.

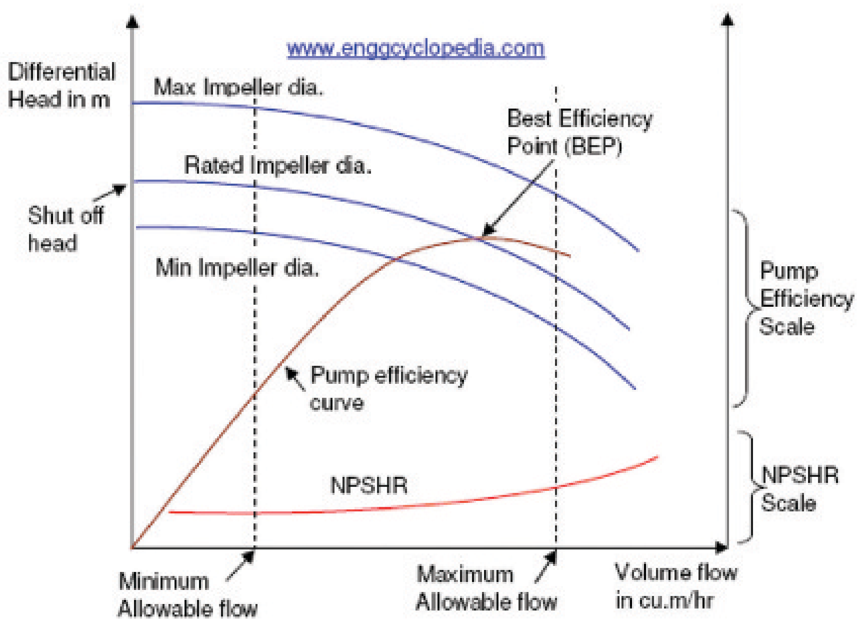

FIGURE 12.4 Pump performance parameters.

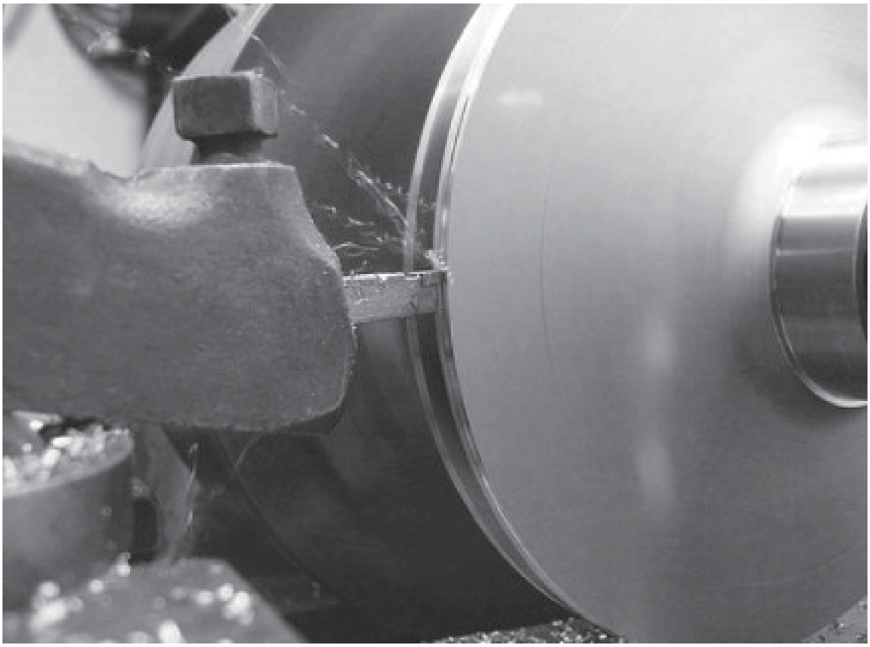

FIGURE 12.5 Trimming of impeller.

12.14 SPEED CONTROLLERS

12.14.1 ADJUSTABLE-SPEED DRIVES (ASDS)

Pumps that experience highly variable demand conditions are often good candidates for ASDs. As pump system demand changes, ASDs adjust the pump speed to meet this demand, thereby saving energy that would otherwise be lost to throttling or bypassing. The resulting energy and maintenance cost savings can often justify the investment costs for the ASD. However, ASDs are not practical for all pump system applications. For example, pump systems that operate at high static head and those that operate for extended periods under low-flow conditions [9].

The most generally used speed controllers are the variable frequency drives. VFDs adjust the electrical frequency of the power supplied to a motor to change the motor's rotational speed. VFDs are by far the most popular type of VSD.

12.14.1.1 Benefits of Speed Controllers

- **Energy Savings:** Energy savings of between 30% and 50% have been achieved in many installations by installing VSDs.
- **Improved Process Control:** By matching pump output flow or pressure directly to the process requirements, small variations can be corrected more rapidly by a VSD than by other control forms, which improves process performance.
- **Improved System Reliability:** Any reduction in speed achieved by using a VSD has major benefits in reducing pump wear, particularly in bearings and seals.

12.15 SUMMARY

The dairy processing industry engaged in the conversion of raw milk to consumable dairy products consumes billion worth of purchased fuels and electricity per year. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high-energy price volatility. The dairy manufacturing industry has radically improved its energy efficiency over the last 20 years through wide upgrading of equipment and the closure of smaller and less efficient factories.

The Pumps in dairies are often operated inefficiently. The reasons will vary from process to process, but the constant outcome is the cost to industry through wasted energy, which runs into millions of rupees per year. Pumping systems account for nearly 20% of the world's energy used by electric motors and 25–50% of the total electrical energy usage in certain industrial facilities. Significant opportunities exist to reduce pumping system energy consumption through smart design, retrofitting, and operating practices. In particular, the many pumping applications with variable-duty requirements offer great potential for savings. The savings often go well beyond energy, and may include improved performance, improved reliability, and reduced life cycle costs.

KEYWORDS

- best operating point
- bypass loops
- cavitation
- centrifugal pump
- cost
- discharge
- energy
- flow rate
- head
- impeller
- impeller trimming
- life cycle cost
- motor
- payback period
- positive displacement pump
- pump curve
- suction
- system curve
- throttling
- throttling valves
- valves
- velocity

REFERENCES

1. Abeberese, B. A. (2012). Electricity cost and firm performance: Evidence from India. *Job Market Paper,* p. 1.
2. Ahmad, Tufail, (1985). *Dairy Plant Engineering and Management*. Kitab Mahal. 5th edition, Allahabad, India.
3. California Energy Commission (CEC) (2002). *Case Study: Pump System Controls Upgrade Saves Energy*. Network Equipment Manufacturing Company's Corporate Campus, Sacramento, CA.

4. Elliot, R. N. (1994). *Electricity Consumption and the Potential for Electric Energy Savings in the Manufacturing Sector*. American Council for an Energy – Efficient Economy, Washington, D. C. Report No. IE-942.
5. Galitsky, C., Worrell, E., Radspieler, A., Healy, P., & Zechiel, S. (2005). *Best Winery Guidebook: Benchmarking and Energy and Water Savings Tool for the Wine Industry*. Lawrence Berkeley National Laboratory, Berkley, CA. Report No. LBNL-3184.
6. http://www.enterprisesurveys.org/Data/ExploreEconomies/2006/india.
7. IEA, 2012. *Energy Prices and Taxes*. Quarterly Statistics, Second Quarter 2012. Paris: IEA.
8. Tutterow, V., D. Casada, and McKane, A. (2000). Profiting from your Pumping System. In: *Proceedings of the 2000 Pump Users Expo*, Louisville, Kentucky.
9. United States Department of Energy (DOE) (2006). *Improving Pumping System Performance, A Sourcebook for Industry*. Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, Washington, D. C. Report DOE/GO-102006–2079.
10. US Department of Energy (US-DOE) (2010). *Federal Energy Management Program, Operation and Maintenance Best Practices: A Guide to Achieving Operational Efficiency*. US Department of energy, p. 225.
11. US Ministry of Energy, Department of Industrial Energy Analysis. 2004. *Variable Speed Pumping – A Guide to Successful Applications*. Executive Summary, US DOE, LBNL-55836, pp. 1–12.
12. US Ministry of Environmental energy, Department of Transport and Regions, (1998). *Energy Savings in Industrial Water Pumping Systems*. Good Practices Guide, New York, p. 24.
13. XEnergy, Inc. (1998). *United States Industrial Electric Motor Systems Market Opportunities Assessment*. Prepared for the United States Department of Energy's Office of Industrial Technology and Oak Ridge National Laboratory. Burlington, Massachusetts.

CHAPTER 13

WATER REQUIREMENTS FOR A DAIRY PLANT: QUALITY AND QUANTITY ISSUES

ARCHANA KHARE, ANIL K. KHARE, and A. K. AGRAWAL

CONTENTS

13.1 INTRODUCTION

Water is an important utility for dairy plants as it governs the hygiene of dairy plants [6]. Water is used in large quantities for cooling, washing and sanitation, production of steam and other operations in dairy plants [4].

Water is also required for cleaning of machines, utensils, floors, etc. The availability of water would certainly affect processing cost of milk and milk products whatever may be the level of production [2]. In the past, abundant and inexpensive sources of water were taken for granted in the dairy processing industry and not much attention was given to economize its use. But, in recent times we have witnessed acute water scarcity in arid and semi-arid regions.

With limited water resources, many dairy plants in such areas find it difficult to operate or otherwise expand their operations. Besides, indiscriminate use of water also results in excessive wastewater generation, which becomes a burden for the dairy in terms of treatment and disposal costs. Dairy processors, therefore, are aggressively challenged to conserve water not only for reducing water consumption but also for employing measures for recovery and recycling of process water, without compromising on the hygienic quality and safety of the products. Once water was easily available commodity at no cost, but now sometimes we need to buy it. The sudden increase in water procurement costs is a matter of great concern today to almost all industries including dairy industry, as it directly affects the production cost [5].

This chapter sheds light on the quality and quantity issues of water requirements in a typical dairy plant.

13.2 STANDARDS FOR QUALITY PARAMETERS OF WATER USED IN DAIRY INDUSTRY

The availability of adequate water of suitable quality is a primary consideration in the selection of site and in the establishment of a dairy processing plant. Water is needed in the processing plant for generating steam, for cleaning, as an ingredient in finished products, as a heat exchange medium in heating and cooling operations, for cleaning plant and equipment, and for protection against fire. There are many sources of water supplies and may be classified as surface water (from lakes, stream and reservoirs) and subsurface water (from shallow and deep wells). The characteristics of water from these sources vary with rainfall, the nature of materials with which the water comes in contact and the time of year [9], as shown in Table 13.1. Water hardness is defined in Table 13.2.

TABLE 13.1 Characteristics of Water from Different Sources

Type	Organic matter	Microbial count	Mineral content
Deep well	Usually low	Usually low	Usually high
Shallow well	Variable	Variable	Ordinarily low
Surface	May be high	May be contaminated	Ordinarily low

TABLE 13.2 Classification of Hardness

ppm of $CaCO_3$	Condition
Less than 50	Soft
50 to 100	Slightly hard
100 to 200	Hard
Above 200	Very hard

Most of the functions of processing plants call for water of a high degree of purity [3]. An overall quality of water cannot be prescribed as so many specialized requirements prevail, so that parameters, that are objectionable for one use, may not necessary prove detrimental for others. In general, only potable water should be used in the preparation of any food intended for human consumption. Portable water is the water which contains no bacteria capable of causing human internal diseases and is esthetically satisfactory for drinking purpose, for example, free from undesirable odors and flavors [17]. The suitability of water for use in dairy processing plant depends upon:

13.2.1 PHYSICAL PROPERTIES

Color – Turbidity should not exceed 10 ppm (silica scale); Odor – should not exceed 20 ppm (cobalt scale); Flavor – free from objectionable odor and taste.

13.2.2 CHEMICAL PROPERTIES

Dissolved solids and gases; pH; and hardness – Calcium and manganese salts cause the hardness in water. Generally, hardness is expressed as ppm of $CaCO_3$, which decides degree of hardness (Table 12.2).

13.2.3 MICROBIOLOGICAL CONTAMINATES

These include algae, and pathogenic and non-pathogenic organisms. The bacteriological quality of water for the plant should meet the standards for drinking water. The fitness of water for drinking purpose with respect to bacterial content is determined by the presence or absence of the coliform group of bacteria that include Escherichia and Aerobatic species which indicate the possibility of fecal contamination of water supply.

The three organisms associated with the fecal matter are: *E. coli communis*, *Streptococcus* sp., and *Cl. welchiio*. The last one usually occurs in the form of spores. Of these, *E. coli* is by far the most abundant. The number present in polluted water may vary widely.

Nonpathogenic organisms present in water may influence flavor and odor, and produce slim and bio-fouling of pipes. A high bacterial court in can cooling water may result in recontamination and spoilage. For instance, an iron bacterium found commonly in water contains iron, and extracts iron continually and accumulates it as iron hydroxide. This may lead to the eventual blocking of pipes or discoloration of products.

The total bacterial count in water considerably influences plant sanitation. The purpose of washing and cleaning equipment is to reduce contamination. Obviously, water used for this purpose should itself have a low bacterial count.

Pure waters, such as those drawn from deep wells or those purified by artificial sources, seldom show the presence of *E. coli* in 100 ml of water. This should therefore be the state of purity. When a sample shows a positive test for *E. coli* in 50 ml, it should be considered as the maximum limit, which can possibly be permitted and it should be free from organic pollution. Nitrate in excess of 40 to 80 ppm justifies careful testing due to possibility of sewage contamination.

13.3 CLASSIFICATION OF WATER IN A DAIRY PLANT [15]

13.3.1 PROCESS WATER

Water is used for direct preparation of products, cleaning purposes and various technical purposes such as: washing/cleaning of equipment, transport of product, dissolution of ingredients, etc. A characteristic of process water is that it comes into contact with product directly or indirectly. Therefore, process water should strictly meet requirement of drinking water standards.

13.3.2 COOLING WATER

Cooling water is the water used for removal of heat from process streams and products. The quality requirements for cooling water used in plate heat exchangers to cool milk is critical, since with this type of equipment there is a risk of failure and leakage of cooling water to product. In such situations, cooling water should be of drinking water quality.

13.3.3 BOILER FEED WATER

Boiler feed water is required for steam production. The main quality requirements are low hardness and low air and carbon dioxide content.

13.3.4 MISCELLANEOUS USE

Other uses of water in a dairy plant are for ancillary purposes such as amenities and gardens, and extraordinary incidents (e.g., fire protection). Depending upon product mix, dairy processing plants can use substantial volumes of water for cleaning of utensils, in cooling towers and other processes.

13.4 ESTIMATION OF QUANTITY OF WATER

Dairy plant use water in all three states: solid (ice), liquid (water) and vapor (steam) [1]. Since the requirements of water for a dairy plant is comparatively large [12], it may be difficult to meet the demand from a municipal supply. It is advisable to have a supplementary source such as bore well or open well with overhead storage facility at a convenient location for distribution within plant. The dairy industry involves processing of raw milk into products such as liquid milk, butter cheese, curd condensed milk, dried milk (milk powder), ice cream casein, etc. Various processes such as chilling, pasteurization, homogenization, evaporation and drying are being used in manufacture of these products. The water is not only needed in these processes but also in the production of milk [7]. The major water requirement during production is in the washing of the floor, drinking needs by the animal, bathing of animal, etc. It has been reported that temperature above and below the critical limit adversely affects physiological processes and decreases milk production by 3 to 10% [4]. With the water sprinkling over the lactating animals heat stress is reduced and thereby milk production can be enhanced. In India out of about 125 million tons of milk production/annum, about 15% of total milk produced is brought in the dairy plants for processing [8]. A small dairy plant may be engaged in processing of raw milk into products such as liquid milk, makkhan, dahi chhana, paneer, mishti dahi, khoa, sandesh, and various chhanna and khoa based sweats, etc.

The processing of milk requires huge amount of water. In a dairy processing plant, lot of water is used mainly to clean the equipment after processing as well as washing floors to maintain good hygiene. This results in generation of large volume of waste water. A proper balance should be observed between maintaining good hygiene and use of water for cleaning to conserve the water. Table 13.3 shows the use of water in different activities/products in a dairy plant. Milk house and parlor waste can be estimated from data found in Table 13.4.

TABLE 13.3 Approximate Water Consumption in a Dairy Plant

Operation	Water requirement ratio (liters of water/liters of milk)
Bottle washing per 100 bottles	75.0
Channa/paneer making	8.0
Floor washing	1.0
Ghee making	12.0
Khoa making	4.0
Milk pasteurization	2.0
Milk reception	1.8
Processing of milk for fluid milk production	6.0
Washing of utensils	2.0

TABLE 13.4 Volume of Milk House and Parlor Wastes

Washing Operation	Water Volume
Bulk Tank	
Automatic wash	190–225 liters per wash
Manual wash	110–150 liters per wash
Miscellaneous equipment	110 liters per day
Pail milkers	110–150 liters per wash
Pipeline, in parlor (Volume is higher for long stanchion barns)	280–470 liters per wash
Cow Wash	
Automatic	4–15 liters per wash per cow
Holding pen (sprinklers)	5 liters per head (depending on nozzle size and pressure)
Manual	1–2 liters per wash per cow
Milkhouse floor	35–70 liters per day
Parlor floor	150–180 liters per day

Source: Dean E. Falk, Extension Dairy Specialist, University of Idaho: http://www.oneplan.org/Stock/DairyWater.asp.

13.5 COMMON REASONS FOR WATER LOSS IN A DAIRY PLANT

13.5.1 RMRD

Manual cleaning of cans with running water hoses; water lubrication of conveyors.

13.5.2 PROCESS SECTION

Operating pasteurizers for short durations; Condensate from pasteurizers allowed to drain; Water being allowed to overflow the balance tank when pasteurizers and other equipment are on rinse; Manual cleaning of separator with running water; Cleaning of milk tanks by high pressure, etc.

13.5.3 MILK FILLING SECTION

Manual cleaning of crates with running water hoses; Machine cooling; water drained.

13.5.4 BUTTER AND GHEE SECTION

Draining of cooling water sprayed over butter churns; Draining of condensate from ghee boilers; Draining of cooling water from settling tanks.

13.5.5 EVAPORATING AND DRYING SECTIONS

Draining of condensate from evaporator; Operating evaporators for short durations and frequent cleaning.

13.5.6 CLEAN-IN-PLACE (CIP) SYSTEMS

CIP done without recirculation or used CIP solutions being drained frequently; CIP systems not recovering final rinse water for reuse as pre-rinse water.

13.6 WATER CONSERVATION IN A DAIRY PLANT

Water conservation in a dairy processing plant gives dual benefits. It lowers the water and energy bill of the plant [12]. It also helps to reduce the effluent treatment cost as all the water from the plant reaches the effluent treatment facility before its disposal. For successful implementation of the water conservation measures, the commitment of management is required. The people involved should consider the water as a raw material with a cost and the management should encourage people to innovate measures for conservation of water. All water for reuse should be screened to reduce solid buildup.

Substantial water wastage can be reduced by using the following technology innovations [13]:

- Use of automatic shut off devices on all water hoses of steam and water mixing batteries.
- Use of high pressure, low volume cleaning systems for cleaning crates, silos, etc.
- Use of recuperation tanks as a part of the CIP system recovering the hot water for reuse as pre- rinse in next CIP cycle.
- Use of automation for CIP system and other operations. It is reported that in an automated dairy plant a saving to the tune of 20–25% can be achieved in the expenditure on water supply.
- Use of continuous rather than batch processes to reduce the frequency of cleaning.
- Use of level controllers switching on/off the pumps to avoid overflow from tanks.
- Use of automatic shut off valves with photo sensors for wash basins/urinals.

13.6.1 WATER REUSE

Besides prevention of water loss, optimization of water use in a dairy plant can also be affected by water reuse for specific application, when possible.

This can reduce the demand on water supply and also reduce volumes of wastewater, the treatment and disposal. Water that is considered suitable for reuse is the one that has been recovered from a processing step, including from the food components, and that after subsequent reconditioning treatment(s), as necessary, is intended to be re(used) in the same, prior, or subsequent food processing operation. Reuse water includes:

- **Recirculate water:** Water reused in a closed loop for the same processing operation (e.g., chilled water, condenser cooling water in circulation, pasteurizer cooling water in circulation, etc.)
- **Reclaimed water:** Water that was originally a constituent of food, has been removed from the food by a process step, and is intended to be subsequently reused in food processing operation (e.g., Condensates from milk evaporators).
- **Recycled water:** Water, other than the first use or reclaimed water, that has been obtained from a food processing operation (e.g., permeate from reverse osmosis plant, CIP final rinse water, etc.) [14].

13.6.2 REQUIREMENTS FOR HYGIENIC REUSE OF PROCESSING WATER IN A DAIRY PLANT

Reuse water shall be safe for its intended use and shall not jeopardize the safety of the product through the introduction of chemical, microbiological or physical contaminants in amounts that represent a health risk to consumer. Reuse water should be introduced into a processing system so that it will not add to microbiological or chemical burden of the product. Such water shall at least meet the microbiological and, as deemed necessary, chemical specifications for potable water. In certain cases, physical specifications may be appropriate. Reuse water should not adversely affect the quality and suitability of the product. Reuse water shall be subjected to ongoing monitoring and testing to ensure safety and quality [14, 16].

The frequency of monitoring and testing are dictated by the source of water or its prior condition and the intended reuse of water; more critical applications normally require greater levels of reconditioning than less critical uses [15]. If reconditioned to potable water quality, distribution of reuse is permitted. Water should be in clearly marked (e.g., different colors) systems, including piping and outlets that are separate from the distribution lines for potable water. Cross-contamination by backflow, back-siphoning, or cross connections from reuse water should be prevented. Reuse water storage vessels, if used, should be properly constructed of materials that will not contaminate the water and should allow for periodic cleaning and sanitizing where appropriate.

Proper maintenance of water reconditioning system is critical to avoid having the systems become source of contamination. For example, filtration systems can become sources of bacteria and their metabolites if bacteria are allowed to grow on entrained organic materials removed from the incoming water; proper maintenance and testing is needed to ensure absence of this situation.

13.6.3 TREATMENT OF REUSE-WATER

To achieve sustainable water management in a dairy factory, both the quantity and quality of water need to be considered. Generally speaking, two scenarios can be distinguished for water reuse: (a) water not in contact with raw, intermediate or final product; (b) typical reuse applications are for cooling purposes and for generation of 'non-food steam' [16].

Water in contact with the products (e.g., water used for cleaning of equipment, reconstitution, washing of products such as butter, cheese and paneer, moisture adjustment in products such as butter, etc.): In some cases, water can be reused without pre-treatment (e.g., the use of condensates as washing water). However, in most cases, water that is recycled or reused will need to be treated to improve its quality particularly when it comes into contact with food or is used to clean surfaces that will come in contact with the products. Advanced water treatment technologies make it possible to treat water to very high degree, significantly reducing potential health risks associated with water reuse. It is even possible to treat wastewater to such a high degree that it can be safely used as a supplement to potable drinking water supplies. However, treating water to a high degree is expensive. The quality of water and the degree of treatment required, should correspond to the intended water use.

While deciding on the type of water treatment system for use, it is important to consider the following points: Reconditioning of water should be under taken with the knowledge of the types of contaminants the water that may have acquired from its previous use. For example, UV disinfection may have limited effectiveness for inactivating protozoan cysts, helminthes or viruses. Similarly, the use of chlorine or ozone on organically enriched water may result in the formation of hazardous organic compounds.

The water treatment system under consideration should be such that it will provide the level of reconditioning appropriate for the intended water reuse. For example, UV disinfection as a sole treatment is not appropriate for water that is turbid or contains particulates because the organisms in the shadow of particles or entrained within particles are protected from lethal effects of the irradiation.

Extremely large volumes of reuse water may justify the use of an advanced wastewater treatment system. Such systems, depending upon the prior state of the water, may require the use of one or more processes such as: filtration, de-nitrification, phosphorus removal, coagulation–sedimentation and disinfection. Overall, matching water quality requirements with the type of water use requires analysis of the critical control points and an evaluation of potential for contamination of food products.

Therefore, in addition to developing a framework for water refuse in food production/processing, where possible water reuse in the factory should be integrated into existing HACCP program.

13.6.4 SOME POSSIBLE USES OF CONDENSATE AND REVERSE OSMOSIS PERMEATE

Possible uses for recovered vapor condensate or reverse osmosis permeate could be divided into three broad classes:

Vapor condensate as a heat source: As boiler feed water, for melting butter in a jacketed tanks; For preheating (through heat exchanger) milk prior to entering evaporator; and for preheating (through heat exchanger) or drying air for spray dryers.

Vapor condensate and reverse osmosis permeate for product washing and product uses: As a cheese curd wash water, as casein wash water; Water for reconstitution of powdered products; Recirculation water for evaporator on failure of product feed; Infiltration water in ultrafiltration installations. However, utilization of vapor condensate and RO permeate for product use need strict collection and treatment practices for food safety and economic reasons. In particular, their bacteriological, chemical and organoleptic characteristics require close monitoring.

Vapor condensate and reverse osmosis permeate as water and heat source: For CIP, pre- and intermediate rinsing instead of potable water use, for preparation of CIP solutions; for cleaning of floors and walls of the building [11]; for external cleaning of milk transport vehicles; for use after cooling, as pump seal water.

To achieve sustainable water management, industry needs to focus on low cost solutions for conservation of water. The feasibility of exploiting potential of rainwater harvesting for meeting the water requirement of dairy plant is discussed in the following sections.

13.7 TECHNOLOGY OF RAINWATER HARVESTING

When natural water cycle is disrupted due to external and man-made factors, it becomes utmost important to trap the rain water before it contaminates beyond recognition or runs off beyond our reach. In India, average rainfall is in range of 600 to 1000 mm [10]. The portion of this water will substantiate the water that is needed for dairy processing. It is estimated that 10,000 to 30,000 liters of rain water per 100 m^2 of land area per year can be collected from roof tops/open areas, depending upon the rainfall in the area.

13.7.1 INSTALLATION OF RAINWATER HARVESTING SYSTEM

- To lay out piping system for collection of rainwater from rooftops and directing it through the filtration system followed by storage. A bypass arrangement is provided to segregate initial rainwater, which may contain surface impurities during first spell.
- Depending on the need, water collected from rooftops and storage, can be treated employing appropriate treatment processes for further conservation to meet specific requirement of potable water.
- In case of permeable strata is available, the rainwater can be directly charged to this strata by constructing percolation well.
- Depending on the site conditions, shallow percolation column can be constructed for charging the ground water.

13.7.2 DESIGN OF RAINWATER HARVESTING SYSTEM

The basic concept for rainwater harvesting involves design of storm water drainage system for effective collection of rainwater, first spell separator (for roof top rain water), grit chambers/arrestors (for land runoff), sand bed filters (arresting silt and other physical impurities), storage tanks/ponds and percolation elements. Engineering design can be easily mastered with practice and based on requirement, depending on the site conditions. Sand filters are designed as conventional filter beds with sand layer followed by layers of pebbles/ uniform sized aggregate of size 25/40 mm, 50/65 mm. The layers are separated by nylon mesh so that they do not mix and filters can be easily serviced. The larger sized pebbles/stones in the lower layers provide holding of water before it is transferred to storage or percolation elements.

13.7.3 COMMON ELEMENTS OF RAINWATER HARVESTING SYSTEM

- Rainwater drainage piping and grid, first spell separate unit, sand filter, storage/ or to the inlet of percolation pit/element.
- Sand filters drum/pit type with media viz. sand, pebbles, stone aggregates in layers.
- Water storage tanks or water body in lieu of it.
- Recharge unit for charging existing dry or operating open/bore well.
- Ground water recharge pits of 1.2 m diameter × 1.8 m deep size filled with sand, pebbles and boulders in layers.
- Ground water recharge pits as above with auger bored percolation column. There can be single or multiple auger bored column of 6 m depth filled with boulders.
- Percolation bore well of depth up to permeable strata with collection tank.

13.8 CASE STUDY

A case study was done for a typical dairy plant of 200,000 liters/day capacity with a site area of around 20 acres, located in zone having 90 cm of rainfall spread over 50 to 60 rainy days. It has been found that with this roof top and land area, the dairy plant has a potential of harvesting rainwater to meet water requirement for 192 days. The maximum possible quantity of water can be harvested into storage tanks, reservoirs or by charging to ground water to meet the requirement. To start with, existing water storage tanks can be used for storage of water or by creating low cost water bodies and subsequent conservation, charge dry or operating wells/bore wells and if the strata permit charge the ground water table with rainwater. The fact remains that water situation cannot improve overnight. However, whatever may be achieved, it will add to the available resource to begin with. Engineering practices can be developed with the experience gained to further conserve maximum possible quantity of rain water.

13.9 CONCLUSIONS

The use of water should be restricted to absolute minimum consistent with maintenance of high degree of cleanliness and sanitation required in a plant. This will reduce direct cost of providing water for processing and consequent cost of treatment of the dairy effluent. Following suggestions are made with a view to conserve water and affect the economy in dairy plant:

a. Providing nozzle attachment to the hose to prevent excessive flow during floor washing.
b. Using water regulating valves where continuous flow is required and solenoid operated valve for intermittent operation.
c. Use of cooling tower for recycling of cooling water.
d. Utilizing water from heat exchangers for truck floor or can washing.
e. Fixing float control valve for maintaining water levels in storage tanks.
f. For effective implementation of water conservation techniques in the dairy plant, a "water master" should be appointed and a new water conservation cell should be created.
g. System of water audit should be implemented and water conservation law should be framed.
h. Standardization of water conservation process should also be listed as a criterion for licensing other assistance to dairy industry.
i. Strong commitment and support from the top management is essential for a successful conservation program.
j. National and state level awards should be instituted for water conservation in order to promote and encourage energy savings.

13.10 SUMMARY

Water is an important utility as it governs the hygiene of dairy plants. The suitability of water for use in dairy processing plant depends upon, physical properties: like color, odor, flavor and turbidity; chemical properties: like dissolved solids and gases, pH and hardness; Microbiological contaminants:

like algae, and pathogenic and non-pathogenic organisms. Most of the functions of processing plants call for water of a high degree of purity. An overall quality of water cannot be prescribed as so many specialized requirements prevail, so that characters that are objectionable for one use may not necessary prove detrimental for others.

In general, only potable water should be used in the preparation of any food intended for human consumption. The dairy processing plants require ample quantity of water for processing of milk and manufacturing of milk products. Water is one of the major services, which required in dairy plants for processing of milk and manufacture of milk products. Quality and quantity of water used in a dairy plant affect significantly cost of processing and energy requirements.

It is estimated that the water requirement of a dairy plant engaged in fluid milk processing is approximately 6 times the quantity of milk handled; in traditional dairy products like khoa 4 times; channa/paneer 8 times; and Ghee requires 12 times quantity of milk handled. Every plant should monitor the water usage and decide whether water used in one process can be utilized in another process. Emphasis should be made on lowest possible use of water in dairy plants to reduce the quantity of waste water coming out and thereby reduce the environment pollution. To achieve sustainable water management, industry needs to focus on low cost solutions for reduction in water consumption. Subsequently, the scope can expand, bringing around infrastructural improvements such as equipment upgrades, efficient water treatment systems.

The feasibility of exploiting potential of rainwater harvesting to meet water demand of a dairy plant is discussed in detail. Beside simple modifications in routine methods of water consumption, suggestions in this chapter include appointment of ‘water master’ (for control on water usage), ‘water audit’ to determine the means of loss of water, fixing of ‘water standards’ (for replicating in other dairy plants) and provision of some incentives (to encourage others to follow water conservation methods). In a nut-shell, there is a strong need to conserve substantial amount of water by adopting proper conservation techniques. The authors of this chapter advocate generating water consciousness and awareness among the producers and processors both.

KEYWORDS

- **boiler feed water**
- **dairy plant**
- **milk**
- **potable water**
- **process water**
- **rainwater harvesting**
- **reuse**
- **reverse osmosis plant**
- **water demand**
- **water loss**

REFERENCES

1. Agrawal, A. K., Sandey, K. K., Uprit, S., Goel, B. K. (2008). Water requirements of a small dairy plant. *Souvenir of National Seminar on "Dairy Engineering for the Cause of Rural India."* Unpublished Report by I. G. Agricultural University, Raipur, India.
2. Ananta Krishnan, C. P., & Simha, N. N. (1987). *Technology and Engineering of Dairy Plant Operations*. Laxmi Publications, Delhi, pp. 70–85.
3. Aneja, R. P., Mathur, B. N., Chandan, R. C., & Banerjee, A. K. (2002). *Technology of Indian Milk Products*. Dairy India Publication, Delhi, pp. 94–96.
4. Anjali, A., & Singh, M. (2006). Effect of water cooling on physiological responses, milk production and composition of murrah buffaloes during hot humid season. *Indian Journal of Dairy Science*, *59*(6), 386–389.
5. Andersen, M., & Kristensen, G. M. (2004). A generic approach to water minimization and reuse in industry – implications in dairy operations. *The Australian Journal of Dairy Technology*, *59*(2), 73.
6. COWI Consulting Engineers and Planners (2000). *Cleaner Production Assessment in Dairy Processing*. United Nations Environmental Program, Division of Technology, Industry and Economics.
7. Das, M. M., Singh, K. K., & Maity, S. B. (2008). Water for livestock production. *Indian Dairyman, 60*(6), 36–39.
8. Hale, N. (2003). *Sources of Wastage in Dairy Plants*. Bulletin of the International Dairy Federation No. 382/2003, IDF, Brussels, pp. 7–30.

9. IDF (1988). *The Quality, Treatment and Use of Condensate and Reverse Osmosis Permeates*. Bulletin of the International Dairy Federation No. 232/1988, IDF, Brussels.
10. Mandloi, R. S. (2005). Rain water harvesting and water conservation-need of the hour. *Indian Dairyman*, *57*(1), 45–47.
11. Narsaiah, K. (2007). Environmental management in dairy processing plant. *Indian Dairyman*, *59*(5), 43–46.
12. Parekh, J. V., & Naware, M. L. (2013). *Technology of Dairy Products*. IBDC Publishers, Lucknow.
13. Porwal, R. K. (1991). Energy conservation in dairy plants: A case study. *Indian Dairyman*, *43*(11), 525–529.
14. *Proposed Draft Guidelines for the Hygienic Reuse of Processing Water in Food Plants*. CX/FH 01/9(2001), 34th Session of Codex Committee on Food Hygiene, Bangkok.
15. Ranganna, S. (1991). *Handbook of Analyzes and Quality Control for Fruit and Vegetable Products*. I[st] Edition. Tata McGraw-Hill Publishing Company Limited.
16. Rausch, K. D., & Powell, G. M. (1997). *Dairy Processing Methods to Reduce Water Use and Liquid Waste Load*. Cooperative Extension Service, Kansas State University.
17. Sharma, K., & Saxena, R. (1991). *Water Management in Dairy Plants (Project Report)*. Institute of Rural Management, Anand.

CHAPTER 14

COMMON UTILITIES FOR THE DAIRY INDUSTRY

VANDANA CHOUBEY

CONTENTS

14.1 INTRODUCTION

Milk is highly perishable and so it requires immediate treatment as soon as it comes out of cow's udder to sustain for a longer period of time. In order to increase its shelf life milk is either chilled or heat treated which involves the use of hot water or steam or cooling or chilled water, etc., depending on the type of treatment. Not only for milk but for its conversion to various products, steam or water or refrigeration or electricity is employed in some or other way. Like for pasteurization, UHT, evaporation, drying, etc. hot water or steam or hot air is required. For cooling, chilling or freezing, refrigeration system is required. For cleaning or even for blending of some ingredients, water is required; and for most of the machinery to work electricity is required. Therefore, these common utilities play a key role for proper functioning of dairy industry.

This chapter will discuss about type and quality of water used in dairy for different purposes: Boilers, electricity and refrigeration system.

14.2 WATER

Water is used in many processes in dairy industry such as cleaning, cooling, pretreatment, and rinsing of equipment or for recombination purpose. The quality of the water depends on its final use. In dairy, water is used in many forms: RO water, demineralized water for direct contact of product and soft water or raw water for cleaning purpose. In order to provide various grades of water, softner, RO and demineralization unit is installed as per requirement and their design may vary according to the end use of water. These units work as follows.

14.2.1 DUAL MEDIA (DM) FILTERING UNIT

Raw water is stored in raw water storage tank, which is chlorinated using sodium hypochlorite for decreasing soluble iron and organic matter. The pH of the water is maintained by dosing alkali and is brought to 7.0 to 8.0 as raw water is generally acidic and pH of 7.5 to 8.0 is required for removal of iron as it gets converted to insoluble form and filtered through filters. Dual media filters are provided to remove insoluble iron and turbidity. Residual chlorine helps to restrict growth of microbiological matter in the filter media. Hence, small quantity of water at outlet of DMF is maintained.

The outlet water of DMF goes through "basket strainer" for fine particle removal and then goes to ultrafilter that removes colloidal silica, organics, coloring matter and left turbidity.

From UF, feed water goes to RO block where feed water is conditioned by different chemicals for de-chlorination and anti-scalant dosing for reducing salt deposition in RO membrane at high concentration level and then the feed passes through a cartridge filter for fine particle removal and then it finally enters the RO block.

14.2.2 RO BLOCK

RO Block consists of pressure tube arrangement with RO membrane. Here, flowrate and feed is forced at required pressure through a high pressure pump. Finally, feed is obtained through two outlets: one is Permeate, for example, the required product with lower TDS (total dissolved solids) and saline water, for example, reject. Then the permeate passes through "Degasser Tower" to wipe out dissolved carbon dioxide.

14.2.3 MIXED BED POLISHER

This unit consists of mixed foam of Cation and Anion resin which is fully charged. Cation resin exchanges Ca, Mg, Na ions for H ions and Anion resin exchanges SO_4, Cl, Silica ions for OH ions.

Hence, mixed bed polisher acts as a unit for removal of ionic impurities and works as polisher after RO block. However, the output obtained depends on the initial load of ions. Mixed bed resins are regenerated in the regeneration cycle by respective regeneration when Mixed bed is exhausted and after regeneration mixed bed unit can be taken back to use. Outlet water of mixed bed is slightly acidic, hence alkali dosing for pH correction is done.

14.3 RO UNIT

RO unit is a separation process that is able to separate dissolved solutes from solvent mostly through pressure driven membrane separation process (Figure 14.1). The solute may range in size from 1–10 angstrom or less and either organic or inorganic in nature. RO is capable of removing 90% of dissolved solute weather organic or inorganic. RO is mostly applicable for treatment of raw water. RO membranes are generally constructed from cellulose, acetate, polyamides or other polymers.

FIGURE 14.1 RO unit.

14.3.1 PROCESS

When salt solution is separated from demineralized water by semi permeable membrane, the salt solution of high osmotic pressure causes flow of demineralized water into salt solution section. The rise in solution water equals osmotic pressure continues to increase as water will flow from water to salt solution. By exerting pressure on the salt solution compartment water can be made to flow in reverse direction. This is reverse osmosis.

14.3.2 OPERATION

The osmosis pressure is based on the specific solute and its concentration in water, practically to produce first drop of pure water from the solution of solute at specific concentration the minimum pressure requirement is osmotic pressure. Very fine pores are used for membrane in reverse osmosis of order 5 angstrom units. The rejection rate of the membrane depends on ionic, for example, higher ionic charge of an ion, the better rejection therefore monovalent salt will pass the membrane at higher rate than multivalent.

For production of permeate and concentrate, pressure is applied to feed the stream by pump. The level of solids is high in concentrates and low in permeates.

14.4 TREATMENT

14.4.1 PRETREATMENT

It is very important to pretreat water before the RO process for removal of chlorine as well as other hardness elements. Hence, softener (removes hardness of water) or other suitable method for treatment must be used to delay hard water scale built up.

14.4.2 RO MEMBRANE

RO membrane stops the passage of the dissolved and suspended solids while letting or allowing the water to pass through. RO efficiently rejects turbidity, colloids and organic matter although this process may foul the membrane. The type of membrane and impurity decides the final product quality.

14.5 BOILERS

Steam is utilized in various heat treatments of dairy industries like pasteurization, sterilization, UHT, evaporation, CIP, etc. and is an excellent medium for conveying heat. In dairy applications, latent heat of steam and some sensible heat of hot water are utilized.

The steam is produced generally from centralized boiler houses. Boilers are pressure vessels designed to produce steam or produce hot water or an enclosed container that provide a means for heat from combustion to be transferred into working media (usually water) or a gas (steam) until it becomes heated.

In an industrial/technical context, the concept "steam boiler" (also referred to as "steam generator") includes the whole complex system for producing steam for use e. g. in a turbine or in industrial process. It includes all the different phases of heat transfer from flames to water/steam mixture (economizer, boiler, super heater, re-heater and air preheater). It also includes different auxiliary systems (e.g., fuel feeding, water treatment, flue gas channels including stack) [1].

When phase changes of the water is discussed, only the liquid-vapor and vapor-liquid phase changes are mentioned, since these are the phase changes that the entire boiler technology is based on [5].

14.5.1 BOILER EFFICIENCY

The boiler efficiency can be determined by the total fuel bunt and the total water evaporated into steam in given period of time or can be stated as the ratio of difference of fuel energy input and energy lost up by stack to the fuel energy input:

$$\eta = \frac{heat\,used\,in\,producing\,steam}{heat\,liberated\,\,from\,\,fuel} = \frac{\mathrm{W\,(H - h)}}{C} \quad (1)$$

where, W = weight of water actually evaporated or steam produced in kg/hr or kg/kg of fuel burnt; H = total heat of steam in kJ/kg of steam corresponding to given working pressure (from steam tables); h = sensible heat of feed water in kJ/kg of steam corresponding to temperature of feed water (from steam tables); C = calorific value of fuel in kJ/kg of fuel.

Guidance for the construction, operation, and maintenance of boilers is provided primarily by the American Society of Mechanical Engineers (ASME), which produces the following resources:

- Rules for construction of heating boilers, *Boiler and Pressure Vessel Code*, Section IV-2007
- Recommended rules for the care and operation of heating boilers, *Boiler and Pressure Vessel Code*, Section VII-2007

Boilers are often one of the largest energy users in a building. For every year, a boiler system goes unattended, boiler costs can increase approximately 10% [4].

The boilers are generally made up of steel Indian Boiler Regulation (IBR) grade and are generally closed vessel type (Figure 14.2). Main function of the boiler is to produce steam through water by combustion of fuels. Fuel is used in food plants mostly for generating process steam and process drying. Natural gas and liquefied propane (LPG) are preferred fuels in food processing, because their combustion gases are not objectionable in

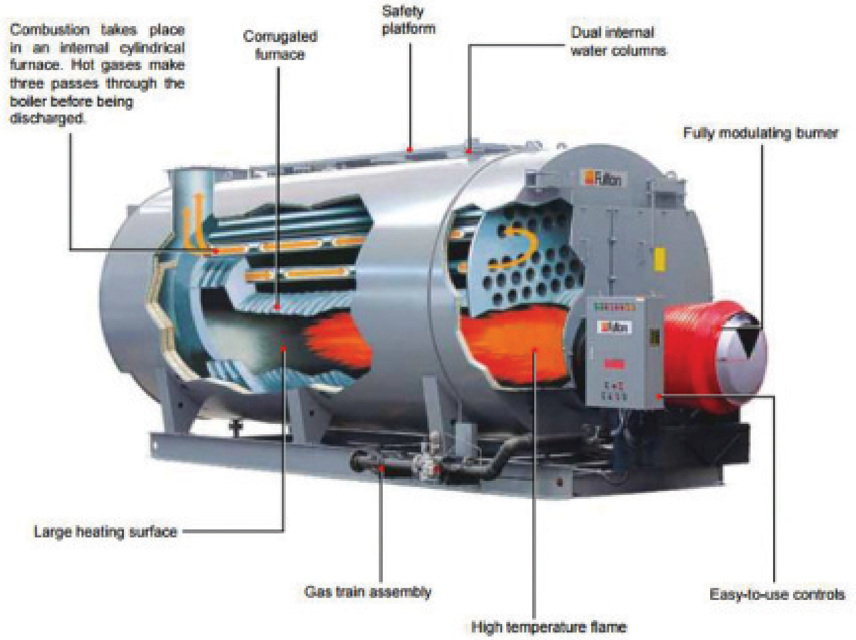

FIGURE 14.2 Cut section of fire tube boiler (Source: http://www.sanelijomiddle.us/industrial/industrial-steam-boiler-diagram)

direct contact with food products. Fuel oil and coal can be used for indirect heating, for example, through heat exchangers. The heating values of the common industrial fuels are [10, 11]:

Natural gas	37.2 MJ/m^3	LPG	50.4 MJ/kg
Fuel oil	41.7 MJ/kg	Anthracite coal	30.2 MJ/kg
Lignite coal	23.2 MJ/kg		

Two main types of steam boilers are used in dairy industries:

1. **Fire tube boilers**: Low-pressure boilers are limited to a maximum working pressure of 15 psig (pound-force per square inch gauge) for steam and 160 psig for hot water [3].
2. **Water tube boilers**: High-pressure boilers are constructed to operate above the limits set for low-pressure boilers, and are typically used for power generation. Operating water temperatures for hot water boilers are limited to 250°F [3].

14.5.2 MAIN COMPONENTS OF A BOILER

14.5.2.1 Boiler Shell

Made up of steel plate bend into cylindrical form and riveted or welded together. The ends of the shell are closed by means of end plate and should have enough space for water and steam.

14.5.2.2 Burner

There are two types of burners:

1. Natural Draft burners or Atmospheric burners.
2. Forced draft burner or power burners.

Now-a-days, low NO_X burners or premix burners are more commonly used as they ensure efficient mixing of air and fuel at the burners entrance and reduce NO_X emissions.

14.5.2.3 Furnace

This is also-called fire box, where fuel is actually burnt (Figure 14.3).

14.5.2.4 Combustion Chamber

Burners are placed here and the combustion process takes place. Temperature inside the combustion chamber increase very rapidly. Combustion chambers are generally made of steel or cast iron.

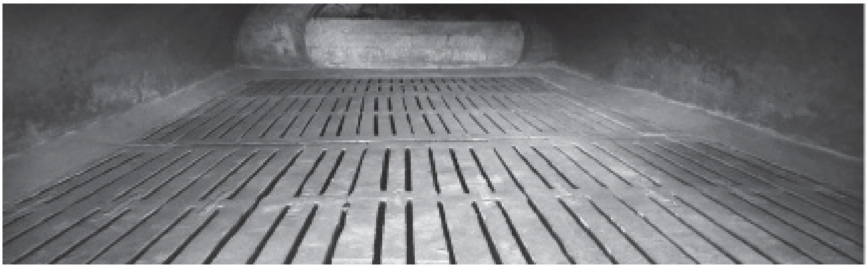

FIGURE 14.3 Furnace.

14.5.2.5 Heat Exchangers

Here, heat transfer takes place that converts water to steam. Heat exchangers (Figure 14.4) can be of steel tube bundle, cast iron. Also some smaller boilers may be made of copper clad steel.

14.5.2.6 Exhaust Stack

It is piping that conveys hot combustion gases away from the boilers to outside. These pipes are generally made of steel or stainless steel.

14.5.2.7 Boiler Mountings

Boiler mountings are mounted on boilers for its proper and safe functioning. All combustion equipment must be operated properly to prevent disasters from occurring, causing personal injury and property loss. The basic cause of boiler explosion is ignition of a combustible gas that has accumulated within the boiler. There is a tremendous amount of stored energy within a boiler. The state change of superheated water from a hot liquid to a vapor (steam) releases an enormous amount of energy. For example, 1 ft^3 of water will expand to 1600 ft^3 when it turns to steam. Therefore, "*if one can capture all the energy released when a 30 gallon home hot water tank flashes into explosive failure at 332°F, one would have enough force to send the average car to a height of nearly 125 feet. This is equivalent to more than the height of a 14 story apartment building, starting with a lift-off velocity of 85 miles per hour*" [7].

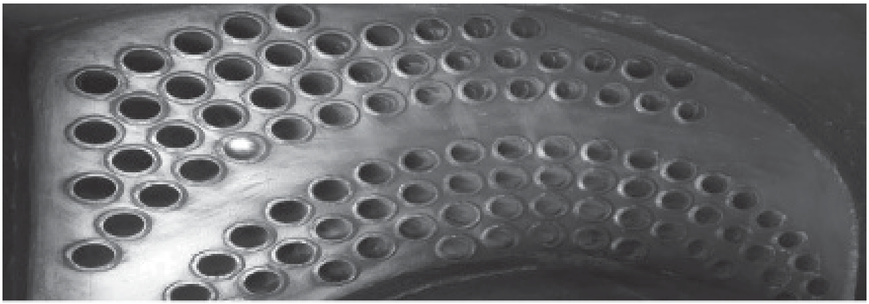

FIGURE 14.4 Heat exchanger.

14.5.2.8 Pressure Gage

Pressure gage measures the pressure of steam inside the boiler. These are generally Bourdon type. The bourdon pressure gage consists of an elastic bourdon tube whose one end is connected to steam space in the boiler and fixed. Due to pressure, the elliptical cross section of the tube tends to round out. Since the tube is encased in circular curve, therefore it tends to become circular. The pointer moves due to the elastic deformation with help of pinion and sector arrangements. The gage pressure is directly shown on the calibrated scale as the pointer moves.

14.5.2.9 Water Level Indicator

It is the safety device generally placed in front. These are two in number to indicate the level of water inside boiler. It consists of 3 cocks and glass tube.

1. **Steam cock** connects glass tube with steam space and kept open during working.
2. **Water cock** connects glass tube with water in boiler and kept open during working.
3. **Drain cock** assures the clarity of steam and water cock and kept closed during working.

14.5.2.10 Flame Detector

It consists of flame rod and ultraviolet or infrared scanner to monitor the flame condition and deactivate the burner in event of non-ignition and other unsafe condition. Flame safeguard controls are programmed to operate the burner and cycle through the stages of operations.

14.5.2.11 Safety Valves

Safety valves blow of the steam when pressure of steam inside the boiler exceeds the working pressure. Safety valves are fitted on the steam chest to prevent explosion, because of extreme internal pressure of steam.

14.5.2.12 Steam Stop Valve

It is usually attached at the highest part of the shell with the help of flange and is the largest valve of the steam boiler. The main function of the steam stop valve is to supply control flow of steam to the main steam pipe from the boiler and to completely shut down steam when steam is not required.

14.5.2.13 Blow Off Cock

This is attached to the bottom of the boiler and consists of body or casing fitted with conical plug. Blow off cock is generally used to discharge mud scale and sediment from the bottom of the boiler and to clear the boiler whenever necessary.

14.5.2.14 Feed Check Valve

This is fitted to the shell little below water level of the boiler and is a non-return valve fitted to screwed spindle to regulate the lift and control the supply of water by feed pump that is pumped into the boiler.

14.5.2.15 Fusible Plug

The main function of the fusible plug is to put off fire in the furnace when the water level in the boiler goes to a very low or unsafe limit and hence avoid explosion that may occur due to over -heating of furnace plate. This is generally placed on furnace crown plate.

14.5.3 BOILER ACCESSORIES

14.5.3.1 Feed Pump

Delivers water to the boiler as water is continuously converted into steam and water pressure is generally kept at 20% higher than that in boiler. For this purpose double acting reciprocating pumps are generally used.

14.5.3.2 Super heater

Placed in the route of flue gases from furnace and uses heat given up by flue gases to superheat steam and increase temperature of saturated steam without increasing its pressure.

14.5.3.3 Economizer

Placed between boiler and chimney; and is used to preheat water by utilizing heat of exhaust from flue gases before leaving the chimney.

14.5.3.4 Air Preheater

Extracts heat from the flue gases and transfer to air a portion of heat that would go wasted and is generally placed between economizer and chimney.

14.5.4 OPERATION OF A BOILER

Boiler uses controlled combustion of the fuel to heat water. The fuel and water are mixed together and with the assistance of ignition device provide platform for combustion. The heat generated through combustion chamber is transferred to water through heat exchangers. Ignition, burner, firing rate, fuel supply, air supply, steam pressure, boiler pressure, and water temperature and exhaust draft are regulated by controls.

Hot water produced is delivered to the equipment throughout the building as it is pumped through pipes. Steam boilers produce steam that flows through pipes from area of high pressure to area of low pressure unaided by any external energy source like pump. Steam can be utilized through heat exchangers by providing heat or directly utilized by steam using equipment.

14.6 ELECTRICITY

Electricity is a main energy source used in the dairy industry. In the food industry, about 25% of the electricity is used for cooling and refrigeration and 48% for machine drive [11]. Mechanical system of refrigerator – compressor is driven by motor. Pumps are one of the most important features of all dairy processing operations. Liquid and semi-liquid dairy products are moved through pumps and motors are required to drive pumps. Non-process uses for space heating, venting, air conditioning, lightening and onsite transport consume about 16% of electricity [9]. Pumps and refrigerator driving motors are major electricity consumers in dairy industry.

14.6.1 TYPES OF ELECTRICAL LOADS

14.6.1.1 Resistance

Alternating current and voltages are supplied by standard utility power systems. During the positive and negative cycle, the alternating current and voltages perform work in load with an electrical resistance. Power product of current and voltage is positive during both positive and negative cycle.

14.6.1.2 Inductance

In a circuit the property of the coil, that opposes a change of current, is inductance. An inductor is without electrical resistance and has a significant effect on power line. The power dissipation and consumption is zero as it takes power from the source and returns power to the source every half cycle.

14.6.1.3 Capacitance

In a circuit the property, that opposes the change of voltage, is capacitance. The power dissipation in capacitor is also zero like an inductor.

The power supplied to resistance loads is real power whereas apparent power can be defined as product of current and voltage (P = I x V). There is real power in resistor but no real power in inductor or capacitor whereas there is a current and voltage through a resistor, indicator and capacitor. In a circuit with resistance load and inductance or capacitance, the apparent power should be bigger than the real power.

14.6.1.4 Electric Motor

Motors are designed for rated frequency, voltage and number of phases. Motor efficiency can be defined as shaft power divided by the electrical input power:

$$\eta = \frac{746\, X\ HP\, output}{Watts\, input} \tag{2}$$

The motor efficiency is mentioned on the name plate of motor. Dairies normally purchase their electric power from local distributors. Generally it is supplied at high voltage, between 3,000 and 30,000 V, but dairies with a power demand of up to approximately 300 kW may also take low-voltage supplies of 200–440 V. The principal components of the electrical system are:

- High voltage switch gear.
- Power transformers.
- Low voltage switch gear.
- Generating set.
- Motor control centers (MCC).

There are several ways to improve the efficiency of an electrical distribution system and a drive system, such as [8]:

- Maintain voltage levels.
- Minimize phase imbalance.
- Maintain a high power factor.
- Identify and fix distribution system losses, particularly resistance loss.
- Select efficient transformers.
- Use adjustable speed motors.
- Select efficient motors.
- Match motor operating speeds.
- Size motor for high energy efficiency.

14.7 REFRIGERATION

The objective is to cool the low temperature source, and the device is named a 'refrigeration machine' [2, 6] or the process for removal of heat from a substance under controlled conditions is termed as refrigeration. Refrigeration means continuous extraction of heat from the body at a lower temperature than its surrounding. The substance that extracts heat from cold body and delivers to hot body is known as refrigerant.

14.7.1 UNITS OF REFRIGERATION

'Ton of refrigeration' is the practical unit of refrigeration and is defined as the amount if refrigeration effect produced by uniform melting of one ton of ice from and at 0°C in 24 hours.

14.7.2 COEFFICIENT OF PERFORMANCE OF A REFRIGERATOR

Coefficient of performance (C.O.P.) is defined as the ratio of heat extracted in refrigerator to the work done on refrigerant.

$$C.O.P. = \frac{Q}{W} \tag{3}$$

where, Q = amount of heat extracted by refrigerator; W= amount of work done.

The basic principle of the most common type of mechanical refrigeration is a cyclic thermodynamic process known as the *Rankine cycle* (William John Macquorn Rankine, 1820–1872, Scottish engineer) or a *vapor compression cycle*. The refrigeration phenomenon may be caused by [12]:

- Evaporation of low pressure liquid at low temperature.
- Expansion of high pressure gas.
- Flow of electric current through an interface of different semi-conductors.
- Chemical reaction.

The refrigeration system may be divided into two categories based on driving power of the system: Mechanical compression refrigeration, and thermal energy driven refrigeration system.

14.7.3 MECHANICAL VAPOR COMPRESSION CYCLE

It is the most commonly used refrigeration system and it consists of following four operations:

1. **Compressor:** The compressor (Figure 14.5) is used to compress the vapor refrigerant of low pressure and temperature from the evaporator drawn in it by suction valve where it is compressed to high pressure and temperature. The high pressure and temperature vapor refrigerant is discharged into condenser through discharge valve.
2. **Condenser:** Here the high pressure and temperature vapor refrigerant is cooled and condensed in coils of pipe (Figure 14.5). The surrounding condensing medium either water or air is used to condense vapor refrigerant. This process takes place as it gives up its latent heat to the condensing medium and converts to liquid refrigerant. The liquid refrigerant obtained here is at high temperature and high pressure.
3. **Receiver:** Before entering the expansion valve the liquid refrigerant is stored in receiver from where it is fed to expansion valve in required quantity.
4. **Expansion valve:** The liquid refrigerant at high pressure and temperature is fed to expansion valve where its pressure and temperature is reduced and is fed to evaporator at controlled rate some of the liquid refrigerant evaporates as it enters the expansion valve but most of the liquid changes to vapor in evaporator as it absorbs heat from the region to be cooled.
5. **Evaporator:** The liquid vapor refrigerant at low pressure and temperature in coils of the pipes of evaporator extracts the heat from the outer surface in contact with the coils and cools that area and the transferred heat causes the liquid refrigerant to convert to vapor refrigerant of low pressure and temperature (Figure 14.5).

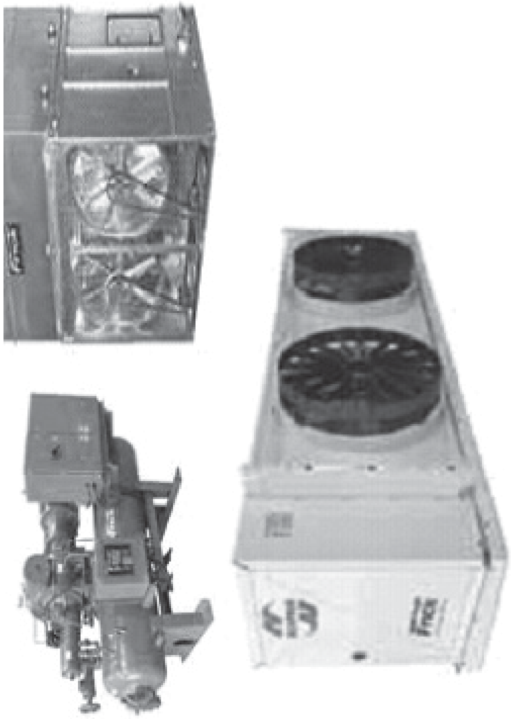

FIGURE 14.5 Compressor (top left), condenser (top right) and evaporator (bottom).

In evaporator the liquid vapor refrigerant absorbs its latent heat of vapor from the medium which is to be cooled. From here vapor refrigerant at low pressure and temperature is fed to the compressor and this way the cycle goes on.

The four processes of the cycle (Figure 14.6) are:

1–2 Isentropic compression process: The refrigerant is compressed isentropically, for example, no heat is absorbed or rejected whereas pressure increases, temperature increases and volume decreases.

2–3 Isothermal compression procession: Here the refrigerant is compressed isothermally which means that the temperature remains constant. Here the pressure increases and the volume decreases and heat is rejected by refrigerant.

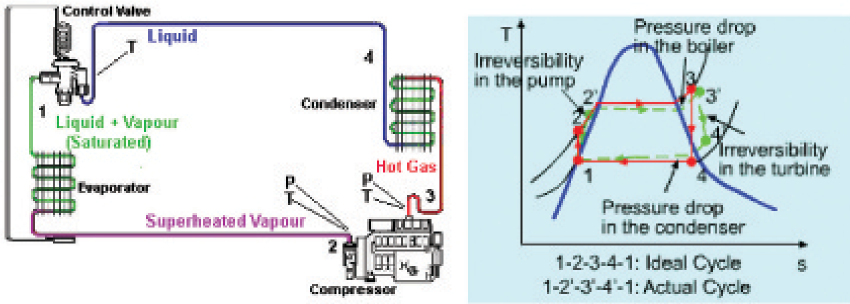

FIGURE 14.6 Left: Vapor – compression cycle; and Right: T – S diagram. (Source: **Left:** [http://pallrefrigerationrajpura.synthasite.com/; **Right:** https://ecourses.ou.edu/cgi-bin/ebook.cgi?doc=&topic=th&chap_sec=10.1&page=theory)

3–4 Isentropic expansion process: The refrigerant is now expanded isentropically, for example, no heat is absorbed or rejected whereas pressure decreases, temperature decreases and volume increases. Here no heat is absorbed or rejected by refrigerant.

4–1 Isothermal expansion process: The refrigerant is expanded isothermally. Here the volume increases and pressure decreases whereas the temperature remains constant and heat is absorbed by the refrigerant.

14.8 SUMMARY

The basic important utilities required for a dairy plant are as under: Water, steam, refrigeration, electricity, and air. When the product flow chart has been planned and checked, the approximate requirements for water, steam, refrigeration, electricity, air and other services can be calculated. With this information, much of the service equipment can be selected. Out of these, steam and electricity are the most important utilities considered for the dairy plant operations.

Steam systems are part of almost every major industrial process today. The steam, in turn, is used to heat processes, to concentrate and distil liquids, or is used directly as a feedstock. All of the major industrial energy users devote significant proportions of their fossil fuel consumption to steam production: food processing (57%), pulp and paper (81%), chemicals (42%), petroleum refining (23%), and primary metals (10%). Steam can be regenerated through waste heat recovery from processes, cogeneration, and boilers [2]. Steam has high capacity to store energy in the form of heat and move it in a controlled amount easily and efficiently throughout a manufacturing facility. Due to this, steam is a popular choice for a wide variety of industrial uses. So proper understanding for the efficient generation, transmission and utilization of the steam is necessary.

It is well known that no large-scale industry can exist without electricity. Modern dairy plants depend on electricity for lighting, heating and power drive for the equipment. With the increased use of electricity, the danger of accident and breakdown at any point has also increased. The need for trained laborers and technical personnel for efficient operation, supervision and maintenance has also increased to a great extent. Even the manager and shift superintendent of a milk plant are expected to have clear conception of basic facts regarding electric supply and tariff.

For procuring electricity, there are two sources: one of power generating plant at the site, and another of purchasing required amount of power from private supply company or State Electrical Board. The first one is only adopted where there is no second choice or alternative. The main reason is that the generation of power in small amount is very costly and there is additional cost involved for installation of generation plant. It is found that electric power can be purchased on permanent basis from nearby Supply Company at reasonable rates.

KEYWORDS

- **boiler**
- **boiler accessories**
- **boiler efficiency**
- **boiler mountings**
- **C.O.P. of refrigeration**
- **DM**
- **electricity**

- **rankine cycle**
- **refrigeration**
- **refrigeration cycle**
- **RO**
- **types of electrical load**
- **types of refrigeration system**
- **water**

REFERENCES

1. Ahonen, V. (1978). Höyrytekniikka II. *Otakustantamo*, Espoo.
2. ASHRAE (2006). *ASHRAE Refrigeration Handbook*. ASHRAE, New York.
3. ASHRAE (2008). *ASHRAE Handbook: HVAC Systems and Equipment*.
4. Capehart, B., Turner, W., & Kennedy, W., (2006). *Guide to Energy Management*.
5. Combustion Engineering. In: *Combustion: Fossil Power Systems*. 3rd ed. Windsor. (1981).
6. Dosset, R. J., & Horan, T. J. (2001). *Principles of Refrigeration*. 5th edn. Prentice Hall, New Jersey.
7. *FEMP O&M Best Practices: A Guide to Achieving Operational Efficiency*, U.S. Department of Energy, August 2010. http://www1.eere.energy.gov/femp/pdfs/omguide_complete.pdf.
8. Lobodovsky, K. K. (2006). Electric energy management. Chapter 11. In: *Energy Management Handbook* (6th ed.), edited by Turner, W. C., & Doty, S., Lilburn, GA: The Fairmont Press, Inc.
9. Okos, M., Rao, N., Drecher, S., Rode, M., & Kozak, J. (1998). *Energy Usage in the Food Industry*. American Council for an Energy-Efficient Economy (ACEEE). Available at: http://www.aceee.org/pubs/ie981.htm.
10. Robberts, T. C. (2002). *Food Plant Engineering Systems*. CRC Press.
11. Saravacos, G. D., & Kostaropoulos, A. E. (2002). *Handbook of Food Processing Equipment*. Kluwer Academic/Plenum.
12. Sun, D. W., & Wang, L. J. (2001). Novel refrigeration cycles. In: *Advances in Food Refrigeration,* edited by Sun, D. W., pp. 1–69. Leatherhead Publishing. UK: Leatherhead.

INDEX

D

E

F

G

H

I

N

O

P